# ATMOSPHERIC TRACER STUDIES TO CHARACTERIZE THE TRANSPORT AND DISPERSION OF POLLUTANTS IN THE CALIFORNIA DELTA REGION

## VOLUME I

## PRESENTATION AND DISCUSSION OF RESULTS

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# SUMMARY

Eight atmospheric tracer studies, utilizing $CBrF_3$ and/or $SF_6$, were conducted from August 31, 1976, through September 14, 1976, within the California Delta Region during four designated meteorological periods. The purpose of these tests was to quantitatively determine the transport and dispersion characteristics of the air passing over the Montezuma Hills. The data base was comprehensive enough to permit accurate mass balances of the tracer; essentially all of the tracer was accounted for by this analysis. Due to the steadiness of the winds, the plume trajectories at 10 km and 50 km downwind of the Montezuma Hills were found to be quite similar. On the average, plumes emitted from the Montezuma Hills during the test periods were transported southeast over Stockton. As a result of the steady nature of the winds, the commonly used Hino correction was found to grossly underestimate the hourly-averaged tracer concentrations computed from 10-second averaged concentrations. A comparison of experimentally determined dispersion parameters with those associated with Pasquill atmospheric stability classes indicated that atmospheric stability generally decreases with increasing distance downwind from the Montezuma Hills. In spite of the complex meteorology and terrain, estimates of tracer concentrations based upon the Gaussian plume model were found to be reasonably accurate. A nomograph was developed to permit rapid calculation of non-reactive pollutant concentrations from tracer data and pollutant emission rates; in the case of $NO_2$, the oxidation of NO to $NO_2$ was assumed to be rapid relative to the transport time. The nomograph was used to predict ground level concentrations of pollutants resulting from the projected emissions associated with the proposed Dow complex in the Montezuma Hills. A reasonable correlation was found to exist between the horizontal standard deviation of the wind, $\sigma_\theta$, and the horizontal dispersion parameter of the plume, $\sigma_y$. Air parcel trajectories, based upon Goodin's (1977) numerical solution to the two-dimensional mass balance equation were found to be in excellent agreement with the tracer data. The correlation between $\sigma_\theta$ and $\sigma_y$, along with the trajectory analysis provide a means for extending the results of this study to other periods of the year. This investigation indicates where emissions from the Montezuma Hills should be monitored. Finally, these results suggest that further study regarding the chemistry, transport and dispersion of pollutants entering the San Joaquin Valley will be of considerable interest.

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# 1. Introduction

## 1.1 Industrialization of the California Delta Region

Interbasin air flow between the Bay Area of San Francisco and the Sacramento and San Joaquin Valleys of central California is characterized during the summer months by a sharp low-level temperature inversion (Miller, 1968) and a strong diurnal sea breeze (Fosberg and Schroeder, 1966). A northern component of the marine air flows through the Bay Area, channels into the Carquinez Strait and fans across the Delta region of the Sacramento and San Joaquin Rivers (Smalley, 1957). Ultimately, the air passing over the heavily populated and industrialized Bay Area passes from the Delta region into the Sacramento and San Joaquin Valleys. The presence of large industrial complexes, projected for construction in the Montezuma Hills of the Delta region, may add to the levels of atmospheric pollutants already present in the air passing through the area. The existence of the urban centers upwind and downwind of the proposed construction sites, the rugged terrain surrounding the Bay Area, and the complex meteorological patterns in the region prohibit simple predictions of the impact associated with future industrialization. An analysis of the extent of adverse impact upon air quality which may result from industrial development of the Montezuma Hills requires a study of the transport and dispersion of pollutants emitted within the Delta region and the Bay Area. The use of atmospheric tracer techniques, utilizing gaseous tracers such as $SF_6$ and $CBrF_3$, provides a relatively simple and inexpensive means to obtain important data which can be used to assist in the impact analysis. The results from eight full-scale

tracer studies conducted in the California Delta Region (shown in Figure 1) during September, 1976, are presented in this report. The cost of these tracer studies was less than .02% of the capital investments required for the construction of just one of the proposed industrial facilities.

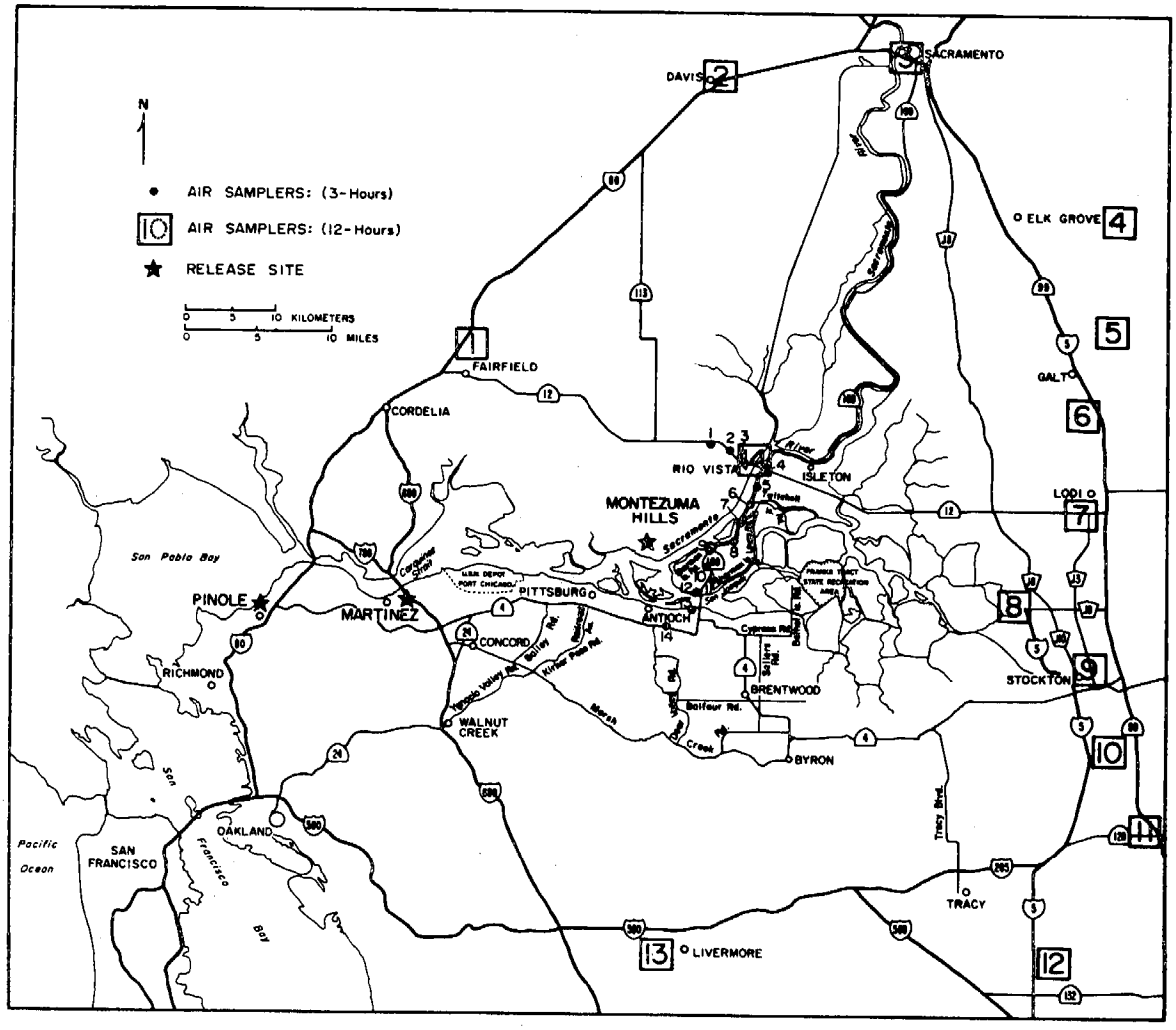



Figure 1. The California Delta Region.

## 1.2 Literature Review

The transport and dispersion of pollutants under complex topographical and meteorological conditions have been the concern of a growing list of workers (Pasquill, 1974). Start, et al. (1974) used tracer techniques in Utah to determine the amount of dilution which occurs for airborne material passing over and around mountains and canyons. They concluded that enhanced mechanical turbulence associated with rough terrain increased dilution over that found in flat regions. Terrain effects were found to increase with increasing stability. Similar conclusions were reached by Giroux, et al. (1974) from a tracer test conducted in southern California. In that test, the $SF_6$ tracer was followed as far as 40 km downwind of the release point. MacReady, et al. (1974) agreed with the preceding reports in suggesting that turbulence was generated from topographical-induced horizontal divergence patterns. From the results of diffusion tests in the Point Arguello area of southern California, Hinds (1970) found that "daytime (unstable) conditions minimized the importance of terrain whereas nighttime (stable) conditions led to apparently significant interactions between terrain and synoptic scale weather events." Angell, et al. (1966,1976) used tetroons to study pollutant trajectories through the southern California air basin. Tetroons released along the coast in some instances were carried out to sea and then, with the diurnal reversal of the winds, swept back into the interior of the basin. In the latter work (1976), tetroons released in early morning near Los Angeles were tracked eastward through the Puente Hills as far as San Bernardino. Other tetroons, released under more

stagnant conditions, moved south before turning east into the Santa Ana Canyon.

Previous work in this laboratory has attempted to characterize the transport and dispersion of pollutants in California coastal areas. Drivas and Shair (1974) released 33.5 Kg of $SF_6$ over 45 minutes from Anaheim, California, and followed the tracer through five neighboring communities as far as Palm Springs, 124 km downwind. These authors (1975) also conducted full-scale tracer studies from power plant stacks in both the Moss Landing and Long Beach coastal zones of California. Afternoon tracer plumes from Moss Landing were observed to move southeast through the Salinas Valley. Afternoon tracer plumes from Long Beach were transported northeast toward Fullerton and Pomona, and then eastward toward San Bernardino. Lamb and Shair (1977) conducted a tracer study from the Oxnard Plain in Ventura County and found that plumes were transported east along the coast and along an inland route into the San Fernando Valley of the Los Angeles Air Basin. These studies reflect the usefulness of tracer techniques in studying the transport and dispersion of pollutants under complex coastal meteorological and topographical conditions.

Fosberg, et al. (1976) attempted to account for the effects of mass divergence upon pollutant dispersion by modifying the well-known Gaussian plume model. Inclusion of a divergence term in the Gaussian expression decreased calculated pollutant concentrations by as much as a factor of two. In other work using the Gaussian plume model, Peters and Richards (1977) developed a scheme to incorporate fast reversible

chemical reactions into dispersion models. Application of the procedure to the conversion of NO to $NO_2$ by reaction with ozone and to the reaction of sulfuric acid with ambient ammonia was presented. This procedure is based on the assumption that local chemical equilibria is achieved at each receptor site. Liu, et al. (1976) showed how to modify the Gaussian dispersion terms to account for the roughness of the terrain. Their derivation of the modified dispersion parameters was based on development of the relationship of the eddy diffusivities and the Gaussian dispersion parameters. Liu, et al. found that for a surface roughness of 50 cm the modified dispersion parameters resulted in a decrease in concentration by a factor of two from the conventional Gaussian model.

Several authors have utilized forms of the diffusion equation to develop dispersion models which take into account the effects of terrain. Roffman and Grimble (1974) developed a three-dimensional model based on successive coordinate transformations where one coordinate was required to be parallel to the flow during each segment of the transport path. Reynolds, et al. (1973) used a coordinate transformation to take into account the irregularity of the floor of the Los Angeles Air Basin.

The experimental studies cited above generally indicate that pollutants are dispersed to a greater extent over complex terrain than over flat surfaces. Furthermore, under stable atmospheric conditions, the effects of terrain upon dispersion and transport are increased over that observed under unstable conditions. Transport paths over complex terrain within complicated meteorological patterns appear to be relatively

difficult to predict on a quantitative basis. Efforts are progressing on the modification and development of atmospheric dispersion models to account for the effects of terrain and meteorology upon the transport and dispersion of pollutants.

## 2. Meteorology and Topography of the California Delta Region

Surface wind patterns from Smalley (1957) indicate that the Carquinez Strait is the major channel for air flow over the Delta Region. During September in the years 1952-1955, the surface wind patterns most prevalent in the area were the west and northwest wind flow types shown in Figure 2. According to Smalley, these patterns occurred 51% of the time, and light and variable winds accounted for 23% of the time. Patterns W5, W2, and W6 were most often observed; they occurred 14%, 10%, and 10% of the time, respectively. These surface patterns show how marine air can become laden with urban pollutants in the Bay Area, pass over the Delta Region, and then turn either north to Sacramento or south to Stockton. Fosberg and Schroeder (1966) explained the onshore summer flow patterns as the result of strong pressure and temperature gradients developed from the coexistence of the eastern Pacific subtropical high pressure area off the coast and a thermal trough in the interior.

Wind flow from the Bay Area through the Delta typically centers around the daily occurrence of an afternoon sea breeze. Fosberg and Schroeder (1966) pointed out that this sea breeze, which is caused by differential heating and cooling of the land and sea, is superimposed upon the summer marine air flow. Miller (1968) noted that the central California sea breeze was accompanied by a sharp, low-level temperature inversion extending inland as far as 40 km. The diurnal cycle can be divided into four periods of the day (Smith, 1976). During Sea Breeze conditions, from approximately 1300 to 1800, winds are relatively strong throughout the area. The average wind speeds at Martinez, Sacramento, and Stockton during the Sea Breeze test periods were respectively, 5 m/sec,

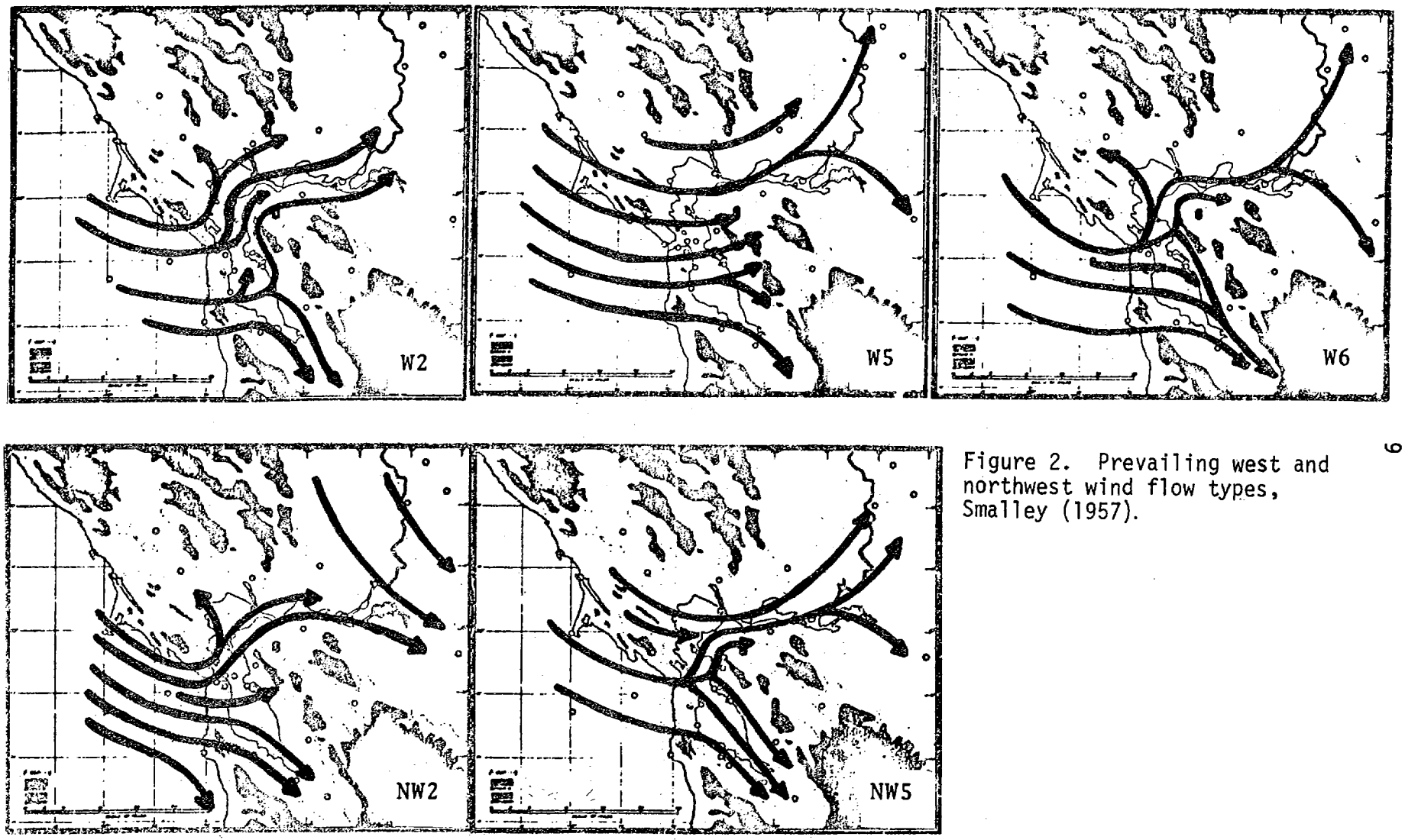



Figure 2. Prevailing west and northwest wind flow types, Smalley (1957).

2 m/sec, 4 m/sec. Smalley noted that wind flow types W5 and W6 accounted for 40% of the patterns observed at 1600 hours. In the afternoon, the mixing depth reaches a maximum due to the heating of the land. Typical afternoon mixing depths during the test period were between 1000 and 3000 meters. This pattern is opposite to that which occurs during Nighttime conditions from approximately midnight to 0500. At night, the height of the mixing layer drops to a minimum, typically between 100 and 500 meters. Air flow stagnates as drainage from the Sierra Nevada Mountains meets the weak sea flow over the Central Valley. According to the Smalley report, light and variable winds occurred during 38% of the measurements taken at 0400; west wind types accounted for 39% of measurements in the early morning. Two transition periods separate the Sea Breeze and Nighttime regimes: Pre-Sea Breeze conditions occur from approximately 0600 to 1100 and are characterized by lifting of the nighttime mixing layer and development of the marine air flow. Wind type W2 was observed in 13% of the patterns at 1000, and light and variable winds were measured during 28% of the time at 1000. Sea Breeze Tail conditions follow the afternoon period and are typified by a decrease in mixing height and a decrease in the strength of the coastal flow. West wind flows in the Smalley work existed in 48% of the observations taken at 2200.

As a result of this summertime meteorological cycle, a strong, relatively constant jet of air issues from the Carquinez Strait and fans out into the reaches of the Delta Region and Central Valley. Fosberg and Schroeder (1966) indicated that the wind surge associated with the invading marine air gains speed as it passes through the Carquinez Strait where it combines with the intensely channeled summer

marine flow. It appears that part of this jet maintains its strength past the Montezuma Hills and then dissipates fairly rapidly just beyond the area. For example, during the two-week test period in early September, the average surface wind speed at the Dow site in the Montezuma Hills was 7 m/sec; further downwind, at Brentwood, the average surface wind speed was 2 m/sec. The daily average wind speeds measured at two levels at the Dow site and at the surface at Brentwood are given in Table 1.

The existence of this jet suggests that material emitted from the Montezuma Hills may be carried into the Central Valley within a narrow, stable stream of air. Material emitted west of the Carquinez Strait into the marine flow may be widely dispersed by the divergence of air from the Strait. Pollutants emitted from sources located very near one another in the vicinity of the Carquinez Strait may be transported along widely different trajectories into the Sacramento or San Joaquin Valleys.

Terrain effects on air flow through the Carquinez Strait appear to be very important in determining pollutant trajectories through the Delta Region. In a Bay Area tracer study utilizing fluorescent particles, Sandberg, et al. (1970) found that the hilly terrain surrounding San Francisco Bay served to deflect westerly marine air flow into the northerly and southerly trajectories apparent in the Smalley wind patterns. Sandberg noted that the presence of low-level temperature inversions enhanced the effects of the Bay Area terrain upon air flow. Results from the tracer study showed that the hilly terrain increased pollutant dispersion, but channeling through such terrain caused higher concentrations to occur locally. The map in Figure 3 shows the topographical contour

TABLE 1

DAILY AVERAGE WIND SUMMARY FOR THE DOW AND BRENTWOOD STATIONS

| Date | Dow (surface) 10 meters | | Dow (tower) 56 meters | | Brentwood (surface) 10 meters | |
|---|---|---|---|---|---|---|
| | Ave. Speed (m/sec) | Prevailing Direction | Ave. Speed (m/sec) | Prevailing Direction | Ave. Speed (m/sec) | Prevailing Direction |
| Aug. 30 | 5.6 | W | 7.2 | W | 2.6 | NW |
| " 31 | 7.3 | W | 8.5 | W | 2.5 | N |
| Sept. 1 | 9.6 | W | 10.2 | W | 2.1 | NNE |
| " 2 | 8.9 | W | 9.7 | W | 2.2 | NNE |
| " 3 | 9.6 | W | 10.7 | W | 2.3 | N |
| " 4 | 8.9 | W | 10.2 | W | 2.3 | NNE |
| " 5 | 8.5 | W | 9.6 | W | 2.3 | N |
| " 6 | 6.8 | W | 7.5 | W | 2.4 | NNE |
| " 7 | 5.8 | NE | 7.6 | N | 3.0 | NNE |
| " 8 | 3.0 | WNW | 4.2 | WNW | 2.9 | NNE |
| " 9 | 5.0 | W | 6.5 | W | 2.5 | N |
| " 10 | 6.3 | W | 7.0 | W | 1.8 | NE |
| " 11 | 5.6 | W | 6.1 | W | - | - |
| " 12 | 5.9 | W | 6.5 | W | 2.3 | NNW |
| " 13 | 6.2 | W | 7.3 | W | 1.7 | NNE |
| " 14 | 8.9 | W | 10.0 | WSW | 3.5 | WSW |
| " 15 | 7.2 | W | 7.7 | W | 2.9 | WSW |
| " 16 | 5.9 | W | 6.9 | W | 1.9 | NW |
| AVE. | 6.9 (m/sec) (16 mph) | | AVE. 8.0 (m/sec) (18 mph) | | AVE. 2.4(m/sec) (5 mph) | |

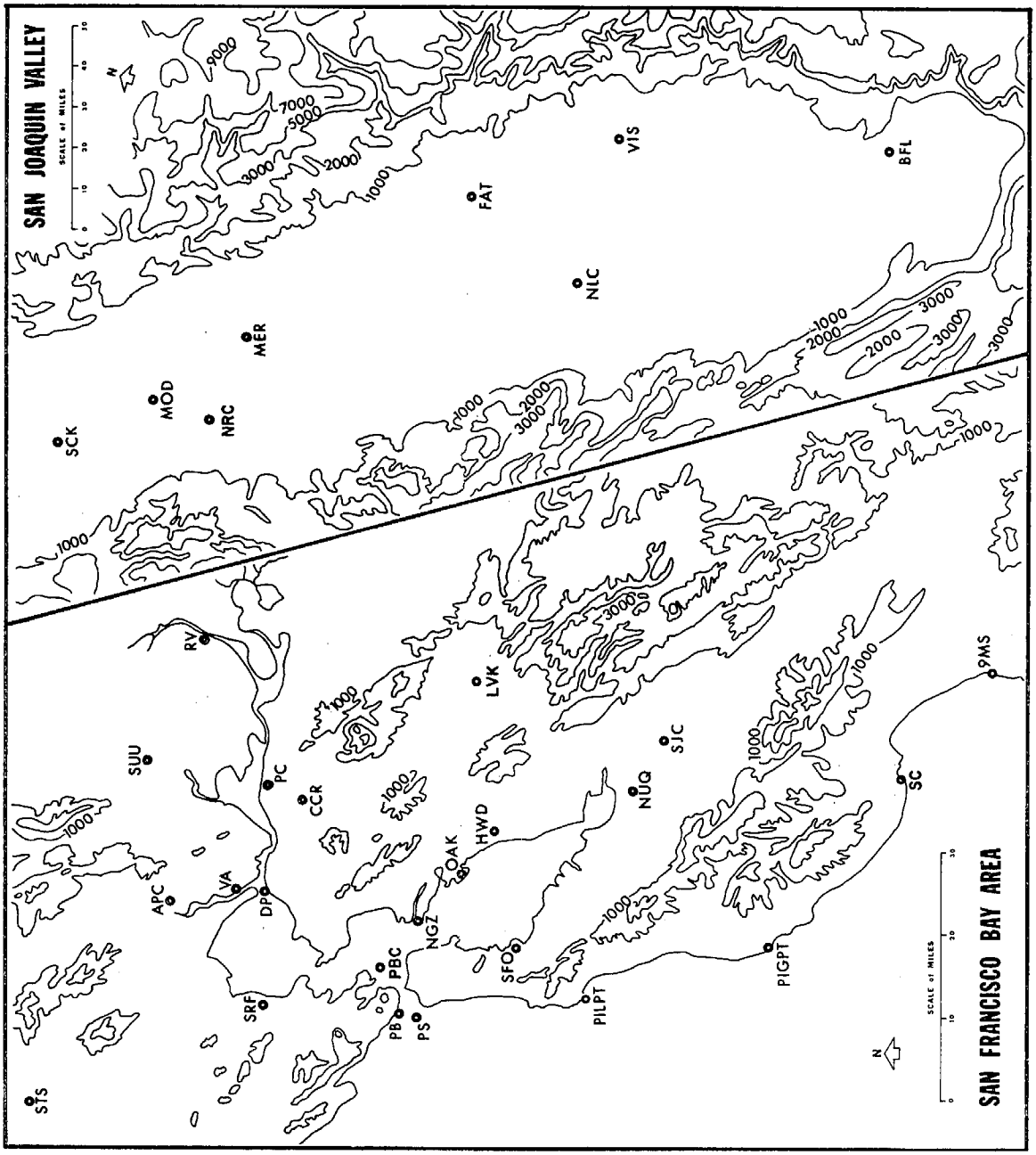



Figure 3. Topographical map of the Bay Area, California Delta, and San Joaquin Valley. Contour lines are given in feet.

lines in 1000 foot intervals for the field study region. Fosberg and Schroeder (1966) found that channeling and deflecting by topographic barriers is extremely noticeable on warm sea breeze days and to a lesser extent on cool days.

# 3. Experimental Procedure

## 3.1 Field Test Design and Schedule

Eight tracer studies were conducted from August 31, 1976, through September 14, 1976, within the Delta Region during the four designated meteorological periods. During seven of the tests, either $SF_6$ or $CBrF_3$ was released from property owned by Dow Chemical in the Montezuma Hills. During the two tests where $CBrF_3$ was used, the $SF_6$ tracer was emitted upstream from Martinez during Test 2 and from Pinole during Test 7 in order to determine the origin and dispersion of the air passing over the Montezuma Hills. The final test involved the release of $SF_6$ from Pinole. Releases from the Dow site covered all four meteorological periods; the releases from Martinez and Pinole were conducted during Sea Breeze and Pre-Sea Breeze conditions. The release schedule, the release locations, and tracer release rates are given in Table 2.

## 3.2 Tracer Release System

Tracers were released at a constant rate from gas cylinders using a manifold, regulator, and large volume flowmeter; the gases were released into the air through 1/2 inch copper tubing at a height of approximately 5 meters. The release system was secured in a truck which provided an easy means of moving the release system to new release locations. Release rates were set using the regulator and calibrated flowmeter; the average release rates listed in Table 2 were determined by weighing the gas cylinders before and after each release, and averaging the weight of the released tracer over the release period. The total amount of tracer released was within 2% of the rate determined from the calibrated rotameter. The release system was continuously monitored during every release.

TABLE 2

TRACER RELEASE DATA

| Date | Test | Location* of $SF_6$ Release | Release Period (PDT) | Release Rate (grams/sec) | Location of $CBrF_3$ Release | Release Period | Release Rate |
|---|---|---|---|---|---|---|---|
| 8/31/76 | 1 | Montezuma Hills | 1200-1700 | 10.6<br>1.01 tons/day | - | - | - |
| 9/2/76 | 2 | Martinez | 1100-1600 | 11.4<br>1.08 tons/day | Montezuma Hills | 1300-1500 | 16.6<br>1.58 tons/day |
| 9/5/76 | 3 | Montezuma Hills | 0000-0500 | 9.5<br>0.90 tons/day | - | - | - |
| 9/6/76 | 4 | Montezuma Hills | 1800-2300 | 10.8<br>1.03 tons/day | - | - | - |
| 9/9/76 | 5 | Montezuma Hills | 1130-1330 | 10.7<br>1.02 tons/day | - | - | - |
| 9/10/76 | 6 | Montezuma Hills | 0600-1100 | 10.5<br>1.00 tons/day | - | - | - |
| 9/13/76 | 7 | Pinole | 0600-1500 | 11.5<br>1.09 tons/day | Montezuma Hills | 0900-1100 | 16.0 |
| | | | | | | 1300-1400 | 16.0<br>1.52 tons/day |
| 9/14/76 | 8 | Pinole | 0730-1300 | 10.9<br>1.04 tons/day | - | - | - |

* Exact Tracer Release Locations: (1) Montezuma Hills: tracer was released from a truck parked by the Dow Chemical air quality monitoring station. The monitoring station is located approximately 4.3 Km east of Collinsville and 2 Km north of the Sacramento River. (2) Martinez: tracer was released from the parking lot of the Mountain View Sanitary District Sewage Plant at the end of Arthur Road. (3) Pinole: tracer was released from the parking lot of the Pinole police station on Pear Street.

## 3.3 Air Sampling Systems

### 3.31 Automobile Traverse System

During each release day, a series of automobile air sampling traverses were conducted using from three to five, two-person teams. Automobile traverses were made by having the passenger in each car take 10-second grab samples in 30 $cm^3$ plastic syringes. Generally, samples were collected every 0.1, 0.2, 0.5 or 1.0 miles, depending upon the distance from the release point and the steadiness of the wind. Descriptions of the traverses are given in Table 3. Traverse paths were determined in the field based upon real time wind data obtained from various data collection agencies and from measurements taken by the traverse personnel. Samples taken during traverses in the early part of each test were analyzed during the test in order to determine the actual plume trajectory.

### 3.32 Airborne Air Sampling System

Personnel from Meteorology Research, Inc. (MRI) obtained air samples in a manner similar to the automobile traverse teams from an airplane traveling downwind of the release at various heights and locations. Air samples were also obtained during spirals from above the mixing layer to the surface. Samples were typically taken at vertical intervals of 100 or 200 feet. During Test 6, Caltrans provided a plane and personnel for three airborne traverses from Sacramento to Stockton. Descriptions of the airborne traverses and spirals are also given in Table 3.

### 3.33 Hourly Averaged Sequential Samplers

A total of 42 sequential air samplers were located at 28 sampling sites; the locations of the sites are shown in Figure 1. Samplers which

TABLE 3

AUTOMOBILE TRAVERSES

| Date | Test No. | Traverse No. | Highway | Direction Traveled | Crossroad | Traverse Time (PDT) | Distance Traveled (km) | No. Samples |
|---|---|---|---|---|---|---|---|---|
| 8/31/76 | 1 | 1 | 99,120,I205 | South, west | Highway 12 | 1400-1450 | 58.7 | 74 |
| | | 2 | 160 | South | Twitchell Island Road | 1420-1433 | 16.7 | 53 |
| | | 3 | 160 | North | Highway 4 | 1430-1445 | 14.8 | 47 |
| | | 4 | 160 | South | Twitchell Island Road | 1515-1527 | 14.8 | 47 |
| | | 5 | I5,120,99 | East, north | Interstate 205 | 1600-1652 | 68.3 | 86 |
| | | 6 | 160 | North | Highway 4 | 1630-1641 | 14.8 | 47 |
| | | 7 | 99,120,I205 | South, west | Boessow Road (Galt) | 1701-1753 | 70.8 | 89 |
| 9/2/76 | 2 | 1 | I680 | South | Interstate 780 | 1130-1143 | 20.0 | 63 |
| | | 2 | I680 | North | Highway 24 (Walnut Creek) | 1215-1228 | 20.0 | 63 |
| | | 3 | 4,160 | East, north | Loveridge Road | 1240-1350 | 25.7 | 17 |
| | | 4 | 160 | North | Highway 4 | 1400-1415 | 18.7 | 59 |
| | | 5 | 160 | South | Highway 12 | 1445-1503 | 18.7 | 59 |
| | | 6 | 160 | North | Highway 4 | 1515-1530 | 18.3 | 39 |
| | | 7 | Railroad Ave. | Southwest | Highway 4 | 1545-1635 | 29.8 | 69 |
| | | 8 | Empire Mine Road | South | Lone Tree Road | 1625-1640 | 10.4 | 14 |

- TABLE 3 (cont.)

AUTOMOBILE TRAVERSES

| Date | Test No. | Traverse No. | Highway | Direction Traveled | Crossroad | Traverse Time (PDT) | Distance Traveled (km) | No. Samples |
|---|---|---|---|---|---|---|---|---|
| 9/2/76 (cont.) | 2 (cont.) | 9 | 99,120,I205 | South | Collier Road | 1630-1715 | 63.6 | 80 |
| | | 10 | I580,I205,120, 99 | East, north | Foothill Road (Dublin) | 1630-1737 | 90.9 | 114 |
| | | 11 | I205,120,99 | East, north | MacArthur Dr. | 1731-1815 | 63.6 | 80 |
| 9/5/76 | 3 | 1 | 160 | North | Highway 4 | 0100-0112 | 18.7 | 59 |
| | | 2 | 99,120 | South, west | Highway 12 | 0130-0210 | 63.6 | 80 |
| | | 3 | 99 | South, west | Boessow Road | 0213-0259 | 63.6 | 80 |
| | | 4 | 160 | South | (Emmaton) | 0240-0300 | 6.6 | 42 |
| | | 5 | 4 | West | Interstate 5 | 0247-0320 | 47.5 | 60 |
| | | 6 | 160 | South | Highway 12 | 0259-0306 | 5.1 | 65 |
| | | 7 | 4 | West | Interstate 5 | 0332-0415 | 63.6 | 80 |
| | | 8 | 4,J3,12 | East, north, west | Byron Road | 0414-0545 | 74.8 | 93 |
| | | 9 | 160 | North | Highway 4 | 0430-0445 | 8.9 | 56 |
| | | 10 | 12,J8 | East, south | Highway 160 | 0432-0517 | 38.1 | 80 |
| | | 11 | 160 | South | Bean pot | 0441-0450 | 6.1 | 77 |
| | | 12 | 160 | North | San Joaquin River | 0502-0511 | 7.6 | 48 |
| | | 13 | 12 | East | Terminous | 0630-0637 | 8.7 | 18 |
| | | 14 | J8 | North | Highway 12 | 0637-0647 | 14.5 | 19 |

TABLE 3 (cont.)

AUTOMOBILE TRAVERSES

| Date | Test No. | Traverse No. | Highway | Direction Traveled | Crossroad | Traverse Time (PDT) | Distance Traveled (km) | No. Samples |
|---|---|---|---|---|---|---|---|---|
| 9/6/76 | 4 | 1 | 160 | South | Highway 12 | 1928-1946 | 18.7 | 59 |
| | | 2 | 99,120,I205 | South, west | Highway 12 | 2130-2217 | 63.6 | 80 |
| | | 3 | 160 | South | Bean pot | 2132-2140 | 6.4 | 80 |
| | | 4 | 99,120,I205 | South, west | Kettleman Lane | 2200-2246 | 63.6 | 80 |
| | | 5 | 160 | North | San Joaquin River Bridge | 2214-2222 | 6.3 | 79 |
| | | 6 | I205,120,99 | East, north | Tracy Blvd. | 2232-2320 | 63.6 | 80 |
| | | 7 | I205,120,99 | East, north | Patterson Pass Rd. (1.4 mi e of) | 2315-2400 | 63.6 | 80 |
| 9/9/76 | 5 | 1 | 4 | East | Railroad Ave. | 1255-1315 | 15.0 | 94 |
| | | 2 | 4, 160 | East, north | Railroad Ave. | 1314-1330 | 25.4 | 80 |
| | | 3 | Sellers Rd., Cypress Rd., Bethel Island Rd. | North, east, north | Highway 4 | 1349-1417 | 14.9 | 38 |
| | | 4 | Balfour Rd. | East | Deer Valley Rd. | 1351-1405 | 12.1 | 26 |
| | | 5 | Marsh Creek Rd. | East | Deer Valley Rd. | 1356-1428 | 35.7 | 75 |
| | | 6 | 160,4 | South, west | Twitchell Island Road | 1359-1416 | 25.4 | 80 |
| | | 7 | Balfour Road | West | Byron Highway | 1413-1426 | 12.1 | 26 |
| | | 8 | Balfour Road | East | Deer Valley Rd. | 1436-1450 | 12.1 | 26 |

TABLE 3 (cont.)

AUTOMOBILE TRAVERSES

| Date | Test No. | Traverse No. | Highway | Direction Traveled | Crossroad | Traverse Time (PDT) | Distance Traveled (km) | No. Samples |
|---|---|---|---|---|---|---|---|---|
| 9/10/76 | 6 | 1 | Sherman Island Road | Southwest | 160 | 0800-0815 | 5.8 | 37 |
| | | 2 | 160 | South | 12 | 0740-0753 | 15.9 | 100 |
| | | 3 | 99,120,I205 | South, west | Highway 12 | 1001-1051 | 63.6 | 80 |
| | | 4 | Sherman Levee Road | South | Highway 160 | 1023-1033 | 9.5 | 60 |
| | | 5 | 99 | South, west | Highway 12 | 1030-1115 | 63.6 | 80 |
| | | 6 | 160 | North | San Joaquin River Bridge | 1022-1033 | 6.4 | 80 |
| | | 7 | 160 | North | San Joaquin River Bridge | 1103-1112 | 6.4 | 80 |
| | | 8 | I205,120,99 | East, north | Patterson Pass Rd. (1.5 mi e of) | 1105-1203 | 63.6 | 80 |
| | | 9 | I205,120,99 | East, north | Tracy Blvd. | 1145-1230 | 63.6 | 80 |
| 9/13/76 | 7 | 1 | 24,I680,I780 | East, north | Highway 13 | 0924-0956 | 48.3 | 100 |
| | | 2 | Sherman Island Road | Northeast | S. end of Sherman Island Rd. | 0940-1155 | 7.0 | 88 |
| | | 3 | 12,160,4 | East, south, west | Interstate 80 | 1113-1217 | 75.6 | 48 |
| | | 4 | I780,I680 | South | Interstate 80 | 1130-1146 | 24.9 | 32 |
| | | 5 | I580,I205,120 | East | Vasco Road | 1335-1458 | 138.4 | 87 |
| | | 6 | I780,I680,24 | South, west | Interstate 80 | 1340-1414 | 51.5 | 33 |

TABLE 3 (cont.)

AUTOMOBILE TRAVERSES

| Date | Test No. | Traverse No. | Highway | Direction Traveled | Crossroad | Traverse Time (PDT) | Distance Traveled (km) | No. Samples |
|---|---|---|---|---|---|---|---|---|
| 9/13/76 (cont.) | 7 (cont.) | 7 | I580 | East | Highway 238 | 1429-1451 | 33.8 | 22 |
| | | 8 | I80,17,238, I580 Vasco, Walnut 4,160,12 | S,S,E,E N,N N,N,W | W. Texas (Fairfield) | 1450-1706 | 191.5 | 120 |
| | | 9 | I580 | West | Highway 84 | 1458-1532 | 33.8 | 22 |
| | | 10 | 24,I680,I780 | East, north | Interstate 580 | 1537-1611 | 53.1 | 34 |
| | | 11 | 99,120,I205, I580 | S, west | Mack Road | 1654-1820 | 132.0 | 83 |
| | | 12 | I580,17 | West, north | Highway 84 | 1835-1901 | 25.7 | 17 |
| 9/14/76 | 8 | 1 | I680 | South | Interstate 80 | 0906-0931 | 38.6 | 49 |
| | | 2 | I680 | North | Highway 24 | 0941-1007 | 38.6 | 49 |
| | | 3 | 12,160,4,24 | E,S,W,S | W. Texas Ave. (Fairfield) | 1047-1151 | 91.7 | 58 |
| | | 4 | I680 | North | Highway 24 (Walnut Creek) | 1154-1220 | 38.6 | 49 |

TABLE 3 (cont.)

AIRBORNE TRAVERSES AND SPIRALS

| Date | Test No. | Traverse No. | Traverse Path and Direction | Altitude (meters, MSL) | Traverse Time | Distance Traveled (km) | No. Samples |
|---|---|---|---|---|---|---|---|
| 9/10/76 | 6 | 1 | VACA-Dixon Airport south to Isleton | 305 | 0934-0946 | 38.1 | 11 |
| | | 2 | Isleton s. to 4 mi. e. of Brentwood | 305 | 0950-1005 | 24.3 | 59 |
| | | 3 | 4 mi. e. of Brentwood s. to I580-I205 junction | 305 | 1012-1020 | 23.1 | 9 |
| | | 4 | I580-I205 junction n. to 4 mi. e. of Brentwood | 183 | 1044-1052 | 23.1 | 8 |
| | | 5 | 4 mi. e. of Brentwood n. to Isleton | 183 | 1054-1107 | 24.3 | 52 |
| | | 6 | Isleton n. to VACA-Dixon Airport | 183 | 1109-1122 | 38.1 | 14 |
| | | 7 | Isleton s. to 4 mi. e. of Brentwood | 427 | 1140-1153 | 24.3 | 25 |
| | | 8 | Junction S.P.T. Co. Railroad & I580 n. to I5 and I205 | 305 | 1229-1235 | 17.8 | 7 |
| | | 9 | I5-I205 n. to Wilson Way & Highway 99 | 305 | 1238-1251 | 27.5 | 27 |
| | | 10 | Sacramento Executive Airport s. to Ripon | 183 | 1000-1039 | 94.1 | 40 |
| | | 11 | Ripon n. to Sacramento Executive Airport | 183 | 1100-1139 | 94.1 | 40 |
| | | 12 | Sacramento Executive Airport s. to Ripon | 183 | 1200-1239 | 94.1 | 40 |

TABLE 3 (cont.)

AIRBORNE TRAVERSES AND SPIRALS

| Date | Test No. | Traverse No. | Traverse Path and Direction | Altitude (meters, MSL) | Traverse Time | Distance Traveled (km) | No. Samples |
|---|---|---|---|---|---|---|---|
| 9/10/76 (cont.) | 6 (cont.) | 13 | Ripon n. to Sacramento Executive Airport | 183 | 1300-1339 | 94.1 | 40 |
| 9/13/76 | 7 | 1 | Cordelia s. to I680 and Highway 24 (Walnut Creek) | 427 | 0736-0748 | 36.5 | 50 |
| | | 2 | I680 and Highway 24 n. to Cordelia | 305 | 0757-0810 | 36.5 | 53 |
| | | 3 | Cordelia s. to I680 and Highway 24 | 183 | 0819-0832 | 36.5 | 53 |
| | | 4 | Cordelia s. to I680 and Highway 24 | 427 | 0906-0918 | 36.5 | 12 |
| | | 5 | I680 & 24 to Cordelia | 305 | 0925-0938 | 36.5 | 53 |
| | | 6 | Cordelia to I680 & 24 | 183 | 0945-0958 | 36.5 | 53 |
| | | 7 | VACA-Dixon Airport s. to Isleton | 183 | 1112-1324 | 38.1 | 26 |
| | | 8 | Isleton s. to I580 & I205 | 183 | 1327-1343 | 47.0 | 62 |
| | | 9 | I205 & I580 n. to Isleton | 305 | 1348-1404 | 47.0 | 68 |
| | | 10 | Isleton n. to VACA-Dixon Airport | 305 | 1409-1422 | 38.1 | 27 |
| | | 11 | VACA-Dixon Airport s. to Isleton s. to I580 & I205 | 427 | 1428-1456 | 85.1 | 55 |
| | | 12 | Livermore Airport East to I5-205 | 457 | 1759-1812 | 44.1 | 27 |
| | | 13 | I5 & I205 Northeast to Stockton Airport | 457 | 1815-1822 | 16.2 | 13 |

TABLE 3 (cont.)

AIRBORNE TRAVERSES AND SPIRALS

| Date | Test No. | Traverse No. | Traverse Path and Direction | Altitude (meters, MSL) | Traverse Time | Distance Traveled (km) | No. Samples | |
|---|---|---|---|---|---|---|---|---|
| 9/13/76 (cont.) | 7 (cont.) | 14 | Stockton Airport n. to 5.7 mi ssw of Sacramento Executive Airport | 457 | 1850-1912 | 66.4 | 45 | |
| 9/14/76 | 8 | 1 | I680-Highway 24 (Walnut Creek) n. to Cordelia | 366 | 0826-0839 | 36.5 | 53 | |
| | | 2 | Cordelia s. to I680-Highway 24 | 274 | 0843-0856 | 36.5 | 53 | |
| | | 3 | I680-24 n. to Cordelia | 183 | 0858-0911 | 36.5 | 53 | |
| | | 4 | Cordelia s. to I680-24 | 427 | 0942-0955 | 36.5 | 27 | |
| | | 5 | I680-24 n. to Cordelia | 305 | 0959-1012 | 36.5 | 52 | |
| | | 6 | Cordelia s. to I680-24 | 183 | 1016-1028 | 36.5 | 51 | 25 |
| | | | SPIRALS | | | | | ΔH (meters) |
| 9/10/76 | 6 | 1 | Over Frank's Tract Recreation Area | 914 to 488 | 1158-1203 | - | 8 | 61 |
| | | 2 | Over Frank's Tract Recreation Area | 472 to 30 | 1203-1208 | - | 31 | 15 |
| 9/13/76 | 7 | 1 | 0.5 mi n. of the Port Chicago Naval Magazine | 914 to 488 | 0845-0850 | - | 8 | 61 |
| | | 2 | 0.5 mi n. of the Port Chicago Naval Magazine | 472 to 15 | 0850-0854 | - | 33 | 15 |

TABLE 3 (cont.)

AIRBORNE TRAVERSES AND SPIRALS

| Date | Test No. | Traverse No. | Traverse Path and Direction | Altitude (meters, MSL) | Traverse Time | Distance Traveled (km) | No. Samples | ΔH (meters) |
|---|---|---|---|---|---|---|---|---|
| 9/13/76 (cont.) | 7 (cont.) | 3 | 0.5 mi n. of the Port Chicago Naval Magazine | 914 to 488 | 1008-1013 | - | 8 | 61 |
| | | 4 | 0.5 mi n. of the Port Chicago Naval Magazine | 457 to 0 | 1013-1017 | - | 31 | 15 |
| | | 5 | Rio Vista | 1829 to 914 | 1518-1526 | - | 16 | 61 |
| | | 6 | Rio Vista | 884 to 30 | 1526-1534 | - | 29 | 31 |
| | | 7 | Tracy | 1829 to 914 | 1553-1559 | - | 16 | 61 |
| | | 8 | Tracy | 884 to 91 | 1559-1603 | - | 27 | 31 |
| | | 9 | Stockton | 1524 to 762 | 1832-1838 | - | 14 | 61 |
| | | 10 | Stockton | 732 to 30 | 1838-1844 | - | 24 | 31 |
| 9/14/76 | 8 | 1 | 0.5 mi n. of Port Chicago Naval Magazine | 1067 to 457 | 0921-0926 | - | 11 | 61 |
| | | 2 | 0.5 mi.n. of Port Chicago Naval Magazine | 442 to 15 | 0926-0930 | - | 29 | 15 |
| | | 3 | 0.5 mi n. of Port Chicago Naval Magazine | 1372 to 457 | 1039-1044 | - | 16 | 61 |
| | | 4 | 0.5 mi n. of Port Chicago Chicago Naval Magazine | 442 to 15 | 1044-1049 | - | 29 | 15 |

permitted the collection of hourly averaged air samples each hour for 12 hours were positioned at 14 locations, primarily along Highway 99. An additional 14 locations along Highway 160, 10 km east of the Dow site, were designated for the positioning of battery-powered samplers which permitted the collection of hourly averaged samples each hour for three hours. These samplers were used during Tests 1 and 2. Table 4 lists the site locations, crosswind distances from a reference point and downwind distances from the three release points.

### 3.4 Chemical Analysis of Air Samples

Air samples were analyzed for $SF_6$ and $CBrF_3$ using electron capture gas chromatography. The tracers were separated in a stainless steel column (39" x 0.25" OD, 0.18" ID) packed with 80-100 mesh 5A Molecular Sieve. Prepurified nitrogen flowing at 10 psig, caused the $SF_6$ to elute in 18 seconds and the $CBrF_3$ to elute in 40 seconds. Both column and detector were operated at ambient temperatures. A typical chromatogram is shown in Figure 4; additional details concerning the gas chromatographs are available elsewhere (Drivas, 1974).

Twelve chromatographs and two digital integrators were set up in a room at the California Holiday Lodge, Fairfield, California. Only eight of the chromatographs were used during the test; four were used to analyze for $SF_6$ alone and four were set up to analyze for both tracers. Field samples were returned each day to the lab for analysis. All of the samples from one test were analyzed before the next test began. Calibration was done using an exponential dilution method. Calibration results show that concentrations down to $10^{-12}$ parts $SF_6$ per part air and $10^{-11}$ parts $CBrF_3$ per part air could be detected at a signal-to-noise ratio of

TABLE 4

LOCATION OF HOURLY AVERAGE SEQUENTIAL SAMPLERS

Hourly Average 12-Hour Sequential Sampling Stations

| Location of 12-Hour Samplers | Distance from Release Points (Km) | | | Distance S. of Sacramento (Km) |
|---|---|---|---|---|
| | Montezuma Hills | Martinez | Pinole | |
| 1 Fairfield | 28.6 | 28.1 | 36.0 | - |
| 2 Davis | 50.4 | 64.6 | 73.7 | - |
| 3 Sacramento | 61.1 | 81.1 | 92.5 | 0 |
| 4 Elk Grove | 59.3 | 84.4 | 99.6 | 18.0 |
| 5 Herald | 54.0 | 80.6 | 96.3 | 29.9 |
| 6 Collier Road | 48.9 | 75.8 | 92.0 | 39.3 |
| 7 Lodi | 46.6 | 73.2 | 90.2 | 49.9 |
| 8 Hammer Lane | 41.3 | 66.6 | 83.9 | 62.7 |
| 9 Stockton | 48.7 | 73.2 | 90.0 | 67.0 |
| 10 French Camp | 51.9 | 74.5 | 91.5 | 76.0 |
| 11 Manteca | 59.3 | 79.6 | 96.3 | 84.8 |
| 12 Tracy | 61.8 | 77.5 | 93.0 | 99.3 |
| 13 Livermore | 44.3 | 47.1 | 59.5 | - |
| 14 Rio Vista | 13.4 | 39.0 | 55.0 | - |

TABLE 4 (cont.)

| 3-hour Boards | Distance from Release Points (Km) | | Distance N. of Highway 4 - Highway 160 Junction (Km) |
|---|---|---|---|
| | Montezuma Hills | Martinez | |
| 1 | 12.2 | 36.2 | 26.4 |
| 2 | 12.9 | 37.5 | 23.8 |
| 3 | 12.9 | 38.3 | 22.2 |
| 4 | 13.7 | 39.5 | 30.0 |
| 5 | 12.4 | 38.3 | 17.9 |
| 6 | 10.9 | 37.0 | 15.0 |
| 7 | 9.4 | 35.5 | 13.4 |
| 8 | 8.1 | 34.2 | 10.9 |
| 9 | 5.8 | 31.4 | 8.8 |
| 10 | 6.1 | 30.9 | 7.4 |
| 11 | 7.6 | 31.2 | 6.1 |
| 12 | 7.1 | 29.1 | 4.2 |
| 13 | 8.4 | 28.6 | 4.2 |
| 14 | 9.4 | 26.1 | 3.4 (south of 4&160) |

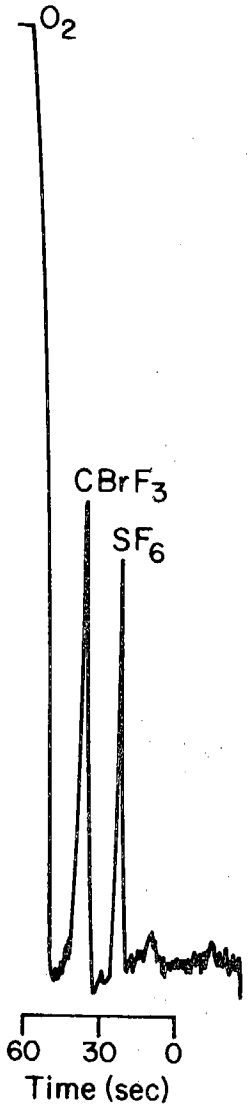



Figure 4. Typical tracer chromatogram: $[SF_6]$ = 6 ppt; $[CBrF_3]$ = 310 ppt.

better than 3 to 1. A typical calibration curve is shown in Figure 5. The chromatogram peaks were integrated with an Autolab System I electronic digital integrator (Spectra-Physics, Santa Clara, California). The gas chromatographs were calibrated before and after the field test period. During the tests, the instruments were cross-checked periodically for reproducibility. The calibration of the tracer data changed by approximately 7% among the gas chromatographs used to analyze $SF_6$ alone. Calibration results for the remaining gas chromatographs changed by 25% for $SF_6$ and 20% for $CBrF_3$. Degradation of the columns and detectors due to atmospheric contaminants in the air samples is the probable cause for the changes in the calibration results. Previous experience has shown that the presence of halogenated solvents in air samples can, over an extended period of use of the chromatograph, contaminate the detector and column. Uncertainty in the tracer data is estimated to range from less than 5% to no more than 25%. Details of the calibration results are given in Appendix A of this volume.

## 3.5 Meteorological Support Systems

### 3.51 Surface Wind Data

Data obtained from MRI were collected from the various agencies listed in Table 5. Table 5 also contains stations maintained by the Bay Area Air Pollution Control District and various industrial companies. The data for these stations were obtained directly from the Bay Area APCD. The data for each station during the test period are tabulated in Table 17 of Volume II, Part B. Measurements from 27 of the 36 wind stations provided hourly averaged wind direction and velocity data; 3 stations measured 2 or 3-hour averaged data. Data from the remaining 6 stations were recorded as single hourly observations. The locations of the stations are shown in Figure 6.

### 3.52 Upper Air Wind Data

Pilot balloon upper air wind speed and direction measurements (pibal measurements) were taken by MRI at the times and locations indicated in Table 5. The data obtained from these measurements are given in Table 18 of Volume II, Part B. MRI also provided estimates of the mixing depth at various locations and times during the test based upon upper air wind and temperature measurements. These data are given in Table 19 of Volume II, Part B. Vector-averaged wind speed and direction data from the surface to the height of the mixing layer are given in Table 20 of Volume II, Part B. The locations of the upper air stations are shown in Figure 6.

TABLE 5

WIND DATA STATIONS AND DESCRIPTION OF WIND DATA

| Station | Station Code | Description of Data |
|---|---|---|
| 1 Dow Surface (Rockwell) | DW01 | Hourly averaged wind speed, wind direction at 5-minute intervals |
| 2 Brentwood (Rockwell) | BR02 | Hourly averaged wind speed, wind direction at 5-minute intervals |
| 3 Venice Ferry (MRI) | VF03 | Hourly averaged speed and direction |
| 4 Rio Cosummes (MRI) | RC04 | Hourly averaged speed and direction |
| 5 Stockton (NWS) | SK05 | Single hourly observations |
| 6 Livermore (NWS) | LV06 | Single hourly observations |
| 7 Rio Vista (NWS) | RV07 | Single hourly observations |
| 8 Sacramento (Metropolitan Airport) (NWS) | SA08 | Single hourly observations |
| 9 Concord (Buchanan Field) (NWS) | CC09 | Single hourly observations |
| 10 Benicia (BAAPCD) | BE10 | Hourly averaged speed and direction |
| 11 Voice of America Radio Tower | VA11 | Hourly averaged speed and direction |
| 12 Pittsburg PG&E Company | PB12 | Hourly averaged speed and direction |
| 13 Martinez Shell Oil | MZ13 | Hourly averaged speed and direction |
| 14 Martinez Lion Oil | MZ14 | Hourly averaged speed and direction |
| 15 Antioch Fibreboard | AT15 | Hourly averaged speed and direction |

TABLE 5 (cont.)

| Station | Station Code | Description of Data |
|---|---|---|
| 16 Benicia Exxon | BE16 | Hourly averaged speed and direction |
| 17 Richmond Allied Chemical | RM17 | Hourly averaged speed and direction |
| 18 Pittsburg Allied Chemical | PB18 | Hourly averaged speed and direction |
| 19 Rodeo Union Oil | RD19 | Hourly averaged speed and direction |
| 20 Concord BAAPCD | CC20 | Hourly averaged speed and direction |
| 21 Vallejo BAAPCD | VL21 | Hourly averaged speed and direction |
| 22 San Rafael BAAPCD | SR22 | Hourly averaged speed and direction |
| 23 San Francisco BAAPCD | SF23 | Hourly averaged speed and direction |
| 24 Redwood City BAAPCD | RC24 | Hourly averaged speed and direction |
| 25 Livermore BAAPCD | LV25 | Hourly averaged speed and direction |
| 26 Fremont BAAPCD | FR26 | Hourly averaged speed and direction |
| 27 Pittsburg BAAPCD | PB27 | Hourly averaged speed and direction |
| 28 Rancho Seco Nuclear Power Plant Site | RS28 | Hourly averaged speed and direction |
| 29 Sacramento Caltrans | SA29 | Hourly averaged speed and direction |
| 30 Davis Caltrans | DV30 | Hourly averaged speed and direction |

TABLE 5 (cont.)

| Station | Station Code | Description of Data |
|---|---|---|
| 31 Wilton<br>Caltrans | WT31 | Hourly averaged speed and direction |
| 32 Rio Vista<br>Yolo-Solano APCD | RV32 | 3-Hourly averaged speed and direction |
| 33 Woodland<br>Yolo-Solano APCD | WD33 | 2-Hourly averaged speed and direction |
| 34 Davis<br>Yolo-Solano APCD | DV34 | 2-Hourly averaged speed and direction |
| 35 Stockton<br>San Joaquin APCD | SK35 | Miles of wind/hr by quadrant |
| 36 Travis<br>Travis Air Force Base | TR36 | Single hourly observations |

TABLE 5 (cont.)

UPPER AIR WIND SPEED AND DIRECTION MEASUREMENTS

| Station | Station Code | Date and Time (PDT) | |
|---|---|---|---|
| Dow Tower | DW50 | Continuous 8/31/76 through 9/14/76 | |
| Dow Pibal | DW51 | 8/31/76 | 1100-1700 |
| | | 9/2/76 | 1000-1700 |
| | | 9/5/76 | 0000-0500 |
| | | 9/6/76 | 1700-2300 |
| | | 9/9/76 | 1100-1400 |
| | | 9/10/76 | 0700-1200 |
| | | 9/13/76 | 0700-1700 |
| | | 9/14/76 | 0800-1600 |
| B & W Resort Pibal | BW52 | 8/31/76 | 1000-1800 |
| | | 9/2/76 | 1000-1800 |
| | | 9/5/76 | 0000-0600 |
| | | 9/6/76 | 1600-2400 |
| | | 9/9/76 | 1000-1400 |
| | | 9/10/76 | 0800-1900 |
| Livermore Pibal | LV53 | 8/31/76 | 1000-1800 |
| | | 9/2/76 | 0900-1000 |
| | | 9/9/76 | 0900-1900 |
| | | 9/10/76 | 1100-1800 |
| | | 9/13/76 | 0800-1800 |
| | | 9/14/76 | 0800-1500 |
| Pinole Pibal | PN54 | 9/13/76 | 0600-1600 |
| | | 9/14/76 | 0600-1700 |
| Junction J2 & CAL4 Pibal | JC55 | 9/14/76 | 1600-1900 |
| Benicia Pibal | BE56 | 9/10/76 | 1400 |
| Rancho Seco Nuclear Power Plant Site Tower | RS57 | Continuous at 200 feet, hourly standard deviation of the wind | |
| Oakland International Airport Pibal | OK58 | 8/31/76 through 9/14/76 2 measurements per day | |

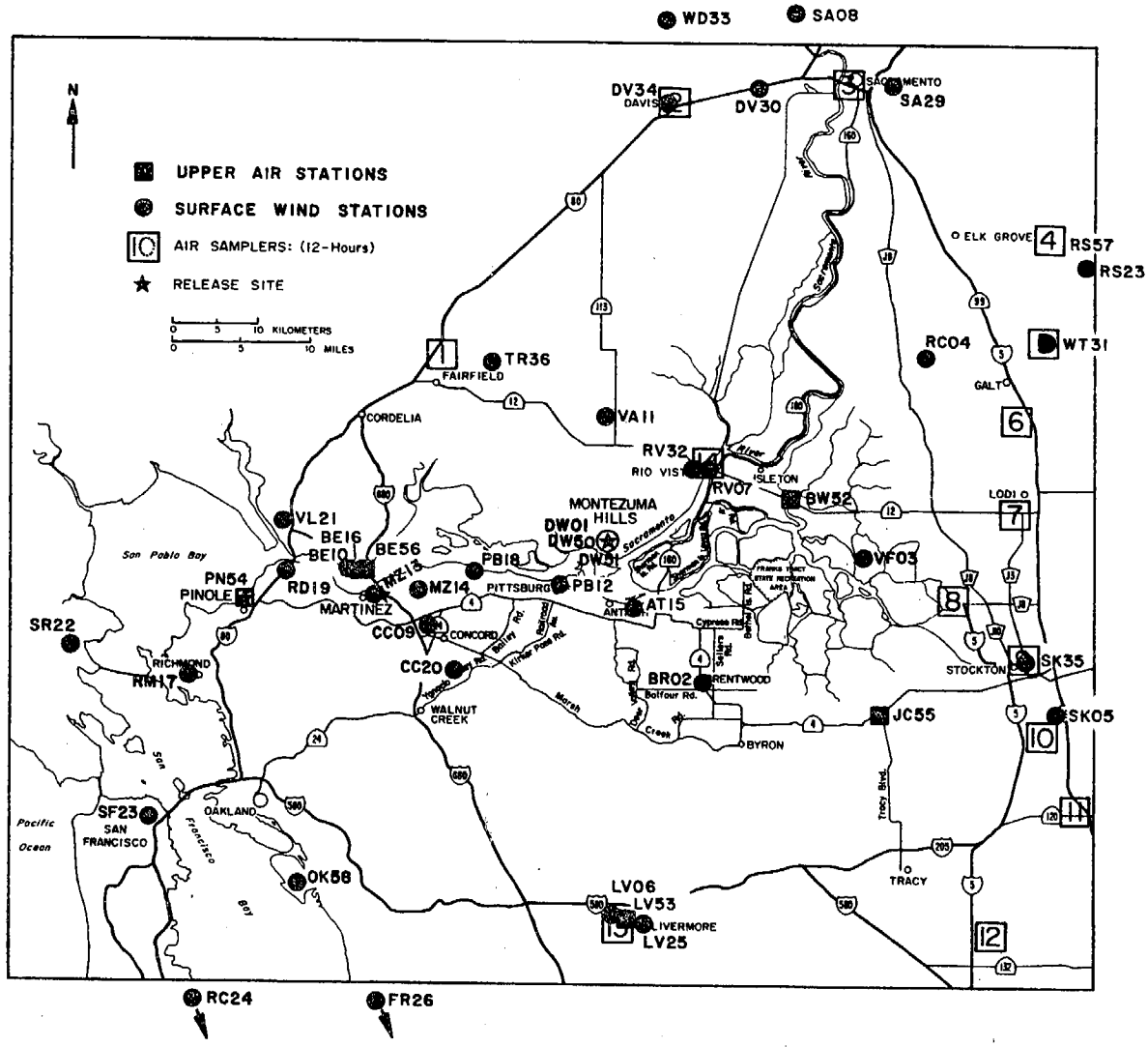



Figure 6. Location of surface wind and upper air data stations.

## 4. Presentation and Discussion of Results

The tracer and meteorological data have been presented graphically in Volume II, Part A, and tabulated in Volume II, Part B, of this report. Results from a portion of the data reduction procedures are also given in Volume II, Part A. In the remainder of this volume, we will present detailed summaries of the qualitative and quantitative results of each test period; we will examine and discuss the atmospheric dispersion characteristics of the Delta Region, and perform a consistency check of the tracer data based on mass balance considerations. We will seek to determine the applicability of the Gaussian plume model to the description of pollutant impact within the test region, and we will present an important relationship between the standard deviation of the wind direction and the Gaussian horizontal dispersion parameter.

### 4.1 Relation of Tracer Data to Industrial Pollutant Emissions

As a means of interpreting the results of the California Delta tracer tests in terms of existing or projected industrial pollutant emissions, we have developed a simple nomograph to be used to convert measured tracer concentrations to pollutant concentrations. Such a conversion necessarily implies that the pollutant emissions of interest are suitably characterized by the tracer release. The conversion of concentrations also implies that either the pollutant is essentially unreactive (like the tracer) or that its rate of reaction is very rapid. For example, carbon monoxide may be considered unreactive over the time scale involved in tracer transport. Sulfur dioxide has been shown to have a relatively slow (15%/hr) reaction rate (Roberts, 1975); nitrogen oxide (NO) can be converted rapidly to nitrogen dioxide ($NO_2$) in the

presence of high oxidant concentrations. In cases like $SO_2$, the conversion of tracer concentrations to pollutant concentrations gives an upper bound on the pollutant concentration. If, as in the example of NO, a pollutant reacts fairly rapidly, then the conversion of tracer concentrations to the product concentrations ($NO_2$) will yield an upper bound on the product concentrations.

The tracer concentrations obtained during the California Delta field study can be converted to pollutant concentrations using the nomographs in Figures 7 and 8. In order to use the nomographs, a value of K, the ratio of the pollutant molecular weight (in grams) to the pollutant's existing or projected emission rate (in tons/day) must be specified. Any tracer concentration measured during the Delta field study can then be converted to the concentration of the pollutant by selecting the point along the specified K-line where the tracer concentration occurs. As examples, the projected emissions of $NO_x$ (as $NO_2$), $SO_2$ and CO associated with the Dow complex have been used to specify the K-lines which are shown in the nomographs. A concentration of 100 ppt $SF_6$ converts to 2.93 ppb $NO_2$, .242 ppb $SO_2$, and .499 ppb CO. In the case of $NO_2$ we have assumed that NO reacts rapidly to form $NO_2$. A summary of the preliminary estimates of emissions from the Dow project are given in Table 6 (Moyer, 1977). A more detailed list is tabulated in Volume II, Part A, Table 6.

The nomographs are based upon the following equation:

$$[P] = [T] \cdot \frac{MW_T}{RR_T} \cdot \frac{RR_P}{MW_P} = [T] \cdot \frac{K_T}{K_P} \qquad (1)$$

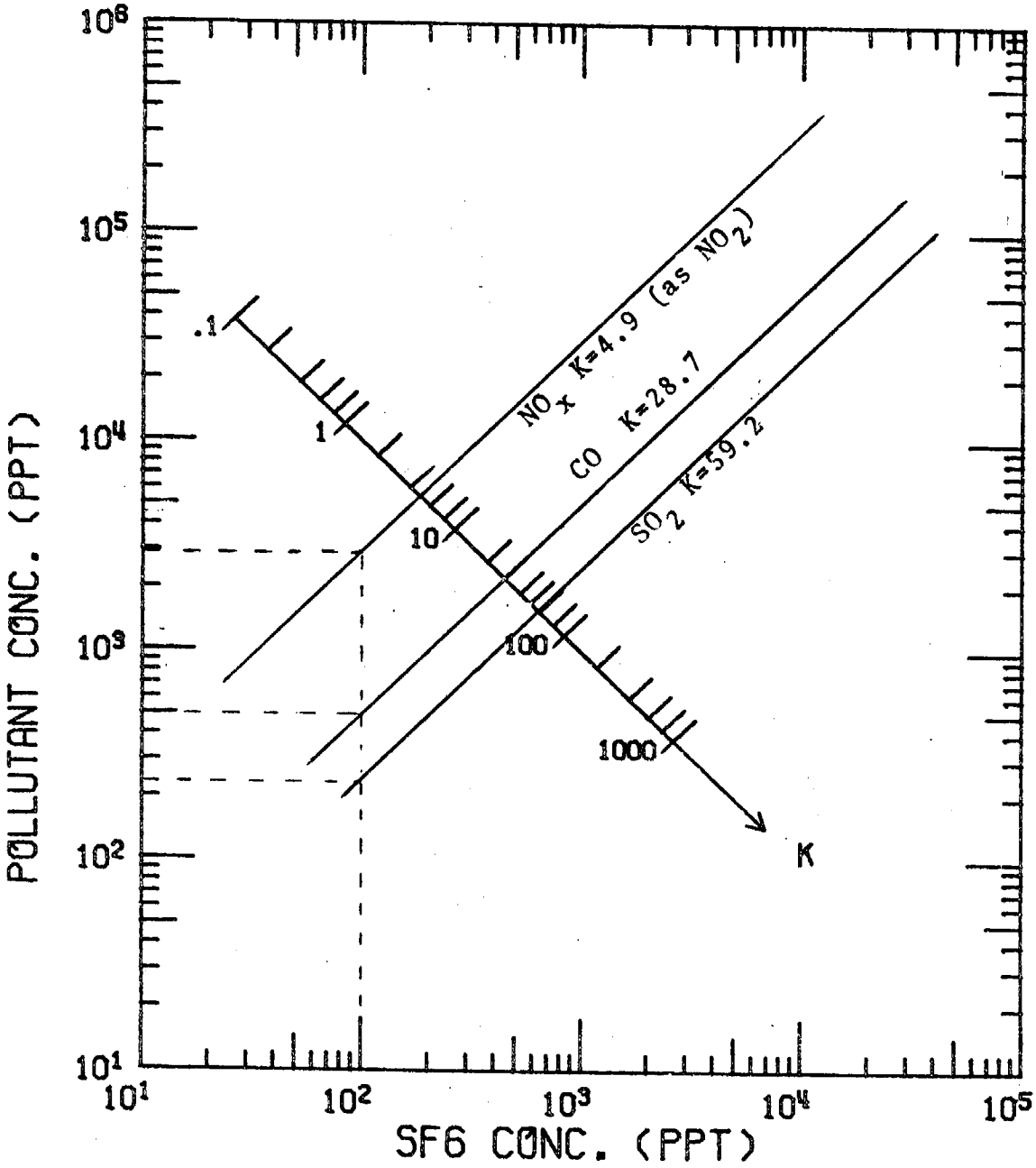



Figure 7. Conversion nomograph for converting $SF_6$ tracer concentrations measured during the field study to pollutant concentrations. K = (pollutant molecular wt., grams) / (pollutant emission rate, tons/day). Values of K shown above are based on projected pollutant emissions from the Montezuma Hills Dow chemical complex. Dashed line indicates the corresponding tracer-to-pollutant concentration conversions.

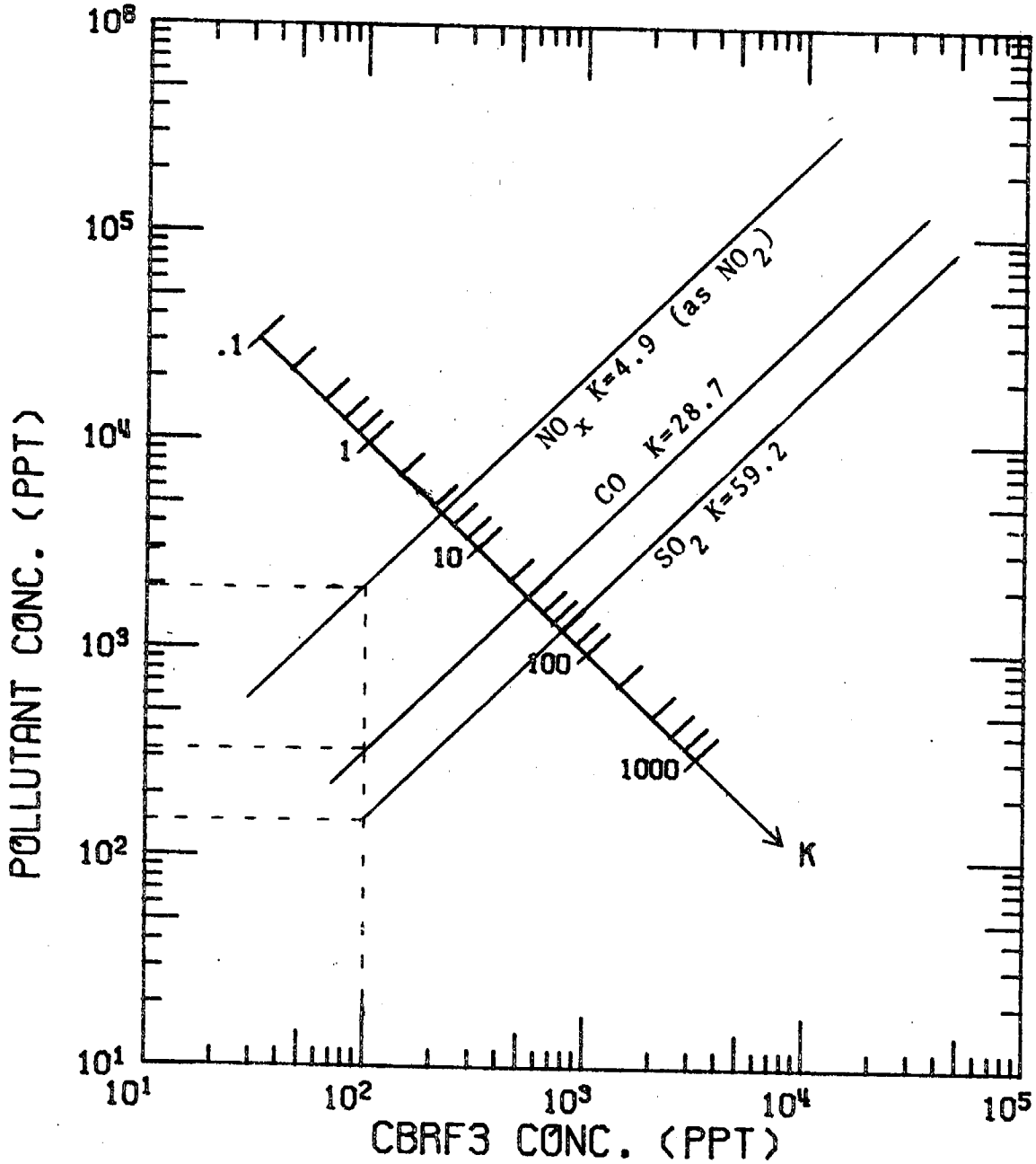



Figure 8. Conversion nomograph for converting $CBrF_3$ tracer concentrations measured during the field study to pollutant concentrations. K = (pollutant molecular wt, grams) / ( pollutant emission rate, tons/day). Values of K shown above are based on projected pollutant emissions from the Montezuma Hills Dow chemical complex. Dashed line indicates the corresonding tracer-to-pollutant concentrations conversions.

TABLE 6

NOMOGRAPH K-VALUES FOR PROJECTED DOW EMISSIONS*

$$K \equiv \frac{\text{Mol. Wt. of Pollutant (grams)}}{\text{Emission Rate (tons/day)}} = \frac{MW_p}{RR_p}$$

| Pollutant | $MW_p$ (grams) | $RR_p$* (tons/day) | K Dow only | $RR_p$** Dow + Turbine | K Dow + Turbine |
|---|---|---|---|---|---|
| $NO_x$ (as $NO_2$) | 46 | 9.41 | 4.89 | 23.10 | 1.99 |
| $SO_2$ | 64 | 1.08 | 59.2 | 1.252 | 51.12 |
| CO | 28 | 0.976 | 28.68 | 4.796 | 5.84 |
| NMHC+ | - | 1.516 | - | 2.900 | - |

$MW_p$ = molecular weight of pollutant (grams/mole)

$RR_p$ = emission rate of pollutant (tons/day)

* Projected Dow emissions for Montezuma Hills chemical complex from Moyer (1977).

** Plans concerning the development of the Dow project indicated a 146 megawatt gas turbine might be necessary as an on-site power source. The emissions resulting from the operation of such a turbine were obtained from Moyer (1977).

\+ Values of K for nonmethane hydrocarbons (NMHC) have not been calculated because the complex reaction mechanisms prevent simple descriptions of the rates of conversion.

where [P] is the pollutant concentration in ppt, [T] is the tracer concentration in ppt, $RR_T$ and $RR_P$ are the tracer and pollutant release rates in tons/day, respectively, and $MW_T$ and $MW_P$ are the associated molecular weights in grams. The terms $K_T$ and $K_P$ are the respective ratios of tracer and pollutant molecular weights to emission rates. The K-lines shown in the nomographs are based on the average tracer release rates during the eight tests (1.02 tons $SF_6$/day, 1.55 tons $CBrF_3$/day). This introduces only a small error (4%) since the release rates were relatively constant from test to test.

Table 7 gives an indication of how emissions from existing sources in the northern Bay Area and near the Montezuma Hills compare with the projected Dow emissions. Pollutant emission rates and the corresponding values of K are listed for the major point sources in the region of interest. These emission rates were taken from the Bay Area APCD Emissions Inventory Summary Report (Base Year, 1975), (Moyer, 1977). We have listed the calculated values of K for these sources as a comparison to the Dow values. Using these values of K to predict pollutant concentrations due to any of the listed sources can only yield a very rough approximation. The tracer source characteristics, in general, may be expected to differ in several important aspects from the source characteristics of these industrial facilities. The effects of the exact location, stack height, or stack velocity are difficult to extrapolate without additional experimental data.

TABLE 7

POLLUTANT EMISSIONS FROM MAJOR POINT SOURCES IN THE NORTHEASTERN BAY AREA

The following list shows the larger point sources and their annual average emissions for 1975. The emissions shown are the total for the whole source site.

The symbol (--) indicates a quantity less than 0.01 Tons/Day.

| 1975 MAJOR SOURCES (NORTHEASTERN BAY AREA APCD) | ANNUAL AVERAGE EMISSIONS (T/D) AND NOMOGRAPH K-VALUES (K = MOLECULAR WT./EMISSION RATE) | | | | | | |
|---|---|---|---|---|---|---|---|
| | ORG | NOX | $K_{NOX}$ | $SO_2$ | $K_{SO_2}$ | CO | $K_{CO}$ |
| ALLIED CHEMICAL CORP. BAY POINT | .04 | .04 | 1200 | 5.6 | 11 | .6 | 47 |
| ANTIOCH BUILDING MATERIALS PITTSBURG | .05 | .01 | 4600 | --- | | .2 | 140 |
| ATLANTIC RICHFIELD BULK PLANT, RICHMOND | .7 | --- | ---- | --- | -- | -- | --- |
| CALIFORNIA & HAWAIIAN SUGAR CO., CROCKETT | .04 | 2.5 | 18 | --- | -- | .3 | 93 |
| CHEVRON CHEMICAL CO. RICHMOND | .2 | .06 | 770 | .03 | 2100 | .2 | 140 |
| COLLIER CARBON & CHEM. CORP., NICHOLS | -- | 2.1 | 22 | 4.1 | 16 | -- | --- |
| CROWN-ZELLERBACH CORP. ANTIOCH | 0.1 | .8 | 58 | .02 | 3200 | -- | --- |
| CROWN CORK & SEAL RICHMOND | .7 | .03 | 1500 | -- | -- | .04 | 700 |
| DOW CHEMICAL COMPANY PITTSBURG | .3 | 4.0 | 12 | .09 | 710 | 1.6 | 18 |
| E. I. DUPONT COMPANY ANTIOCH | .4 | .5 | 92 | -- | 19 | 1.5 | --- |
| EXXON CO., U.S.A. BENICIA | 9.1 | 9.8 | 4.7 | 40 | 1.6 | 4.2 | 6.7 |

$NO_x$ emissions are assumed to be in terms of tons $NO_2$/day.

| 1975 MAJOR SOURCES (NORTHEASTERN BAY AREA APCD) | ANNUAL AVERAGE EMISSIONS - T/D ORG | NOX | $K_{NOX}$ | $SO_2$ | $K_{SO_2}$ | CO | $K_{CO}$ |
|---|---|---|---|---|---|---|---|
| EXXON CO., U.S.A. BULK PLANT, BENICIA | .3 | --- | ---- | --- | ---- | -- | --- |
| FIBREBOARD CORP. ANTIOCH | .6 | .8 | 58 | .03 | 2100 | 22 | 1.3 |
| GLASS CONTAINERS CORP. ANTIOCH | --- | .5 | 92 | .2 | 320 | -- | --- |
| GULF OIL CO. - CALIF. BULK PLANT, HERCULES | 2.5 | 1.3 | 35 | .4 | 160 | -- | --- |
| GULF OIL CO. - CALIF. BULK PLANT, HERCULES | 3.1 | --- | --- | -- | --- | -- | --- |
| HERCULES INC. HERCULES | .02 | .5 | 92 | -- | --- | -- | --- |
| JOHNS-MANVILLE CORP. PITTSBURG | -- | .1 | 460 | -- | --- | -- | --- |
| MARE ISLAND NAVAL SHIPYARD VALLEJO | .4 | .8 | 58 | .03 | 2100 | .04 | 700 |
| MARTINEZ PETROLEUM BULK PLANT, MARTINEZ | .08 | -- | --- | -- | --- | -- | --- |
| MONSANTO COMPANY MARTINEZ | -- | .3 | 150 | 26 | 2.5 | 2.2 | 13 |
| MYERS DRUM COMPANY SAN PABLO | .3 | .01 | 4600 | -- | --- | -- | --- |
| PACIFIC GAS & ELECTRIC CO. (AVON PLANT), AVON | .01 | 3.7 | 12 | 2.8 | 23 | -- | --- |
| PACIFIC GAS & ELECTRIC CO. (CONTRA COSTA PLANT),ANTIOCH | .06 | 11 | 4.2 | 5.4 | 12 | .01 | 2800 |
| PACIFIC GAS & ELECTRIC CO. (PITTSBURG PLANT)PITTSBURG | .1 | 34 | 1.4 | 14 | 4.6 | .03 | 930 |
| PHILLIPS PETROLEUM CO. MARTINEZ | 14 | 9.2 | 5.0 | 18 | 3.6 | .08 | 350 |
| PHILLIPS PETROLEUM CO. BULK PLANT, MARTINEZ | .4 | -- | --- | -- | --- | -- | --- |

| 1975 MJAOR SOURCES (NORTHEASTERN BAY AREA APCD) | ANNUAL AVERAGE EMISSIONS - T/D | | | | | | |
|---|---|---|---|---|---|---|---|
| | ORG | NOX | $K_{NOX}$ | $SO_2$ | $K_{SO_2}$ | CO | $K_{CO}$ |
| QUARRY PRODUCTS, INC. RICHMOND | -- | .02 | 2300 | -- | --- | -- | --- |
| RADIANT COLOR CO. RICHMOND | .2 | -- | --- | -- | --- | -- | --- |
| SAFEWAY STORES, INC. (HOFFMAN BLVD),RICHMOND | .3 | .02 | 2300 | -- | --- | -- | --- |
| SHELL OIL COMPANY MARTINEZ | 20 | 6.9 | 6.7 | 11 | 5.8 | 4.7 | 6.0 |
| STANDARD OIL CO. OF CALIF., RICHMOND | 22 | 20 | 2.3 | 12 | 5.3 | 9.8 | 2.9 |
| STANDARD OIL CO. OF CA. BULK PLANT, AVON | .3 | -- | --- | -- | --- | -- | --- |
| STANDARD OIL CO. OF CA. BULK PLANT, RICHMOND | .5 | -- | --- | -- | --- | -- | --- |
| STAUFFER CHEMICAL CO. MARTINEZ | -- | .05 | 920 | 7.9 | 8.1 | .1 | 280 |
| TEXACO, INC. BULK PLANT, RICHMOND | .4 | -- | --- | -- | --- | -- | --- |
| UNION OIL CO. OF CALIF. RODEO | 10 | 5.1 | 9.0 | 8.2 | 7.8 | 1.4 | 20 |
| UNION OIL CO. OF CALIF. BULK PLANT, RICHMOND | .6 | -- | --- | -- | --- | -- | --- |
| U. S. STEEL CORP. PITTSBURG | .02 | .6 | 77 | -- | --- | .04 | 700 |

## 4.2 Description of the Tracer Tests

In this section, a brief synopsis of each tracer test will be presented. The purpose of the test, the test schedule, and the test meteorology will be outlined; typical results for each test will be presented in the form of overview maps of the automobile and airborne traverse data and the hourly averaged data.

Turner's (1961) method of determining stability class based upon wind speed and insolation was used to classify the stability for each test period. The average insolation or cloud cover, the average wind speed, the average mixing layer depth, and the resulting stability class are given in Table 8. The average wind vector at the tracer release point during the release period is also given.

### 4.21 Tracer Test 1 (8/31/76)

The purpose of the first tracer test was to probe the transport and dispersion of pollutants emitted from the Montezuma Hills under afternoon Sea Breeze conditions. $SF_6$ was released at a steady rate of 10.6 g/sec (1.10 tons/day) from 1200 to 1700 PDT.

The average wind vector at the Dow site during the release was $270^{o}$ at 5.3 m/sec; the overall average wind for the area during the afternoon was $300^{o}$ at 3.4 m/sec. The sky was clear, and Pasquill classes B-C were assumed to exist. The average standard deviation of the wind at Dow was $9^{o}$. The average mixing height during the test was approximately 960 meters, and maximum mixing height reached 2300 m after 1500 PDT. The wind pattern observed at 1600 PDT shown in Figure 9 is typical of the afternoon. The pattern appears to be similar to the Smalley wind flow type NW-5; this pattern occurred 13% of the time in August and

TABLE 8

AVERAGE METEOROLOGICAL CONDITIONS DURING FIELD TESTS

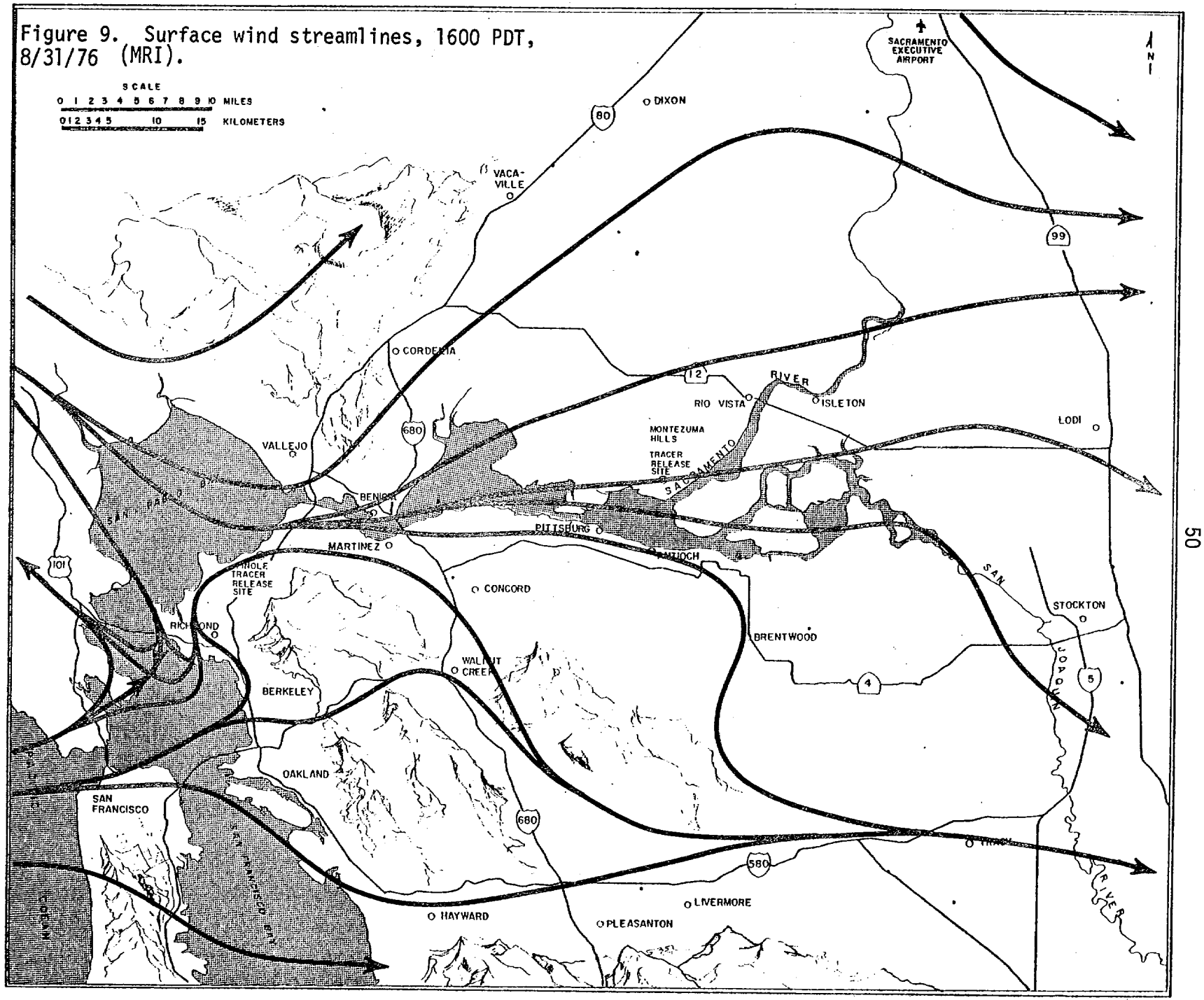
| Test | Time PDT | L* m | u** deg/m/sec | $u_r$*** (release point) | Cloud cover | Stability class |
|---|---|---|---|---|---|---|
| 1 | 1200-1800 | 960 | 300/3.4 | 270/5.3 | clear | B-C |
| 2 | 1100-1700 | 830 | 290/4.3 | 270/4.0 (Mart.) | clear | B-C |
| | 1300-1500 | | | 270/9.2 (Dow) | | |
| 3 | 0000-0600 | 860 | 290/3.3 | 280/9.3 | scattered | D-F |
| 4 | 1800-0000 | 510 | 290/3.3 | 280/7.1 | broken | D-F |
| 5 | 1100-1500 | 1910 | 340/2.6 | 17/1.8 | scattered | B-C |
| 6 | 0600-1400 | 1250 | 270/1.2 | 280/6.3 | overcast | D |
| 7 | 0600-1900 | 830 | 280/2.3 | 240/2.6 (Pinole) | scattered | B-C |
| | | | | 270/4.6 (Dow) | | |
| 8 | 0700-1300 | 1200 | 250/3.6 | 220/3.7 | scattered | B-C |

* The average height of the mixing depth, L, was calculated from available hourly mixing depths for all stations over the indicated time period.

** The average wind direction and speed was obtained by vector averaging data from all downwind stations over the time indicated.

*** $u_r$ is the average wind direction and speed at the tracer release point during the time of the release. Surface data from Rodeo (4 Km northeast of Pinole) were used for determining $u_r$ at Pinole.

Figure 9. Surface wind streamlines, 1600 PDT, 8/31/76 (MRI).



6% of the time over a year in the Smalley study. A quantitatve description of the Test 1 wind patterns and tracer trajectories based upon a numerical solution of the mass balance equation is given in Section 5 of this volume. Peak ozone concentrations in the area reached .16 ppm at Livermore during the afternoon.

Four automobile traverses were conducted along Highway 160 7 km downwind between 1420 and 1641 PDT. The plume crossed Highway 160 approximately 9 km north of the Highway 160-Highway 4 junction. Peak concentrations observed in the traverses ranged from 611 ppt to 1223 ppt. Three automobile traverses were conducted along Highway 99 from Galt to Tracy; the two traverses conducted between 1400 and 1700 PDT indicated the plume had not yet crossed Highway 99. Traverse 7, conducted from 1701 to 1753 PDT, showed the center of the plume, 52 km downwind, to be 6 km east of Tracy at the intersection of I5 and I205. The plume had a centerline concentration of 64 ppt and an observable width of approximately 39 km. Traverses 6 and 7 are shown in Figure 10. As indicated in Traverse 7, emissions from the Dow site ultimately can impact in the San Joaquin Valley, south of Tracy. The average wind speed associated with the transport of the plume from the Montezuma Hills to Highway 99 was about 3 m/sec.

Hourly averaged samples were collected at points along Highway 160 and Highway 99. Peak hourly concentrations along the two routes were 636 ppt and 103 ppt, respectively. The hourly averaged plume crossing Highway 160, 7 km downwind, was centered 8.8 km north of the Highway 160-Highway 4 junction and was approximately 5.6 km wide; hourly crosswind profiles are shown in Figure 11. Further downwind at 45 km, the

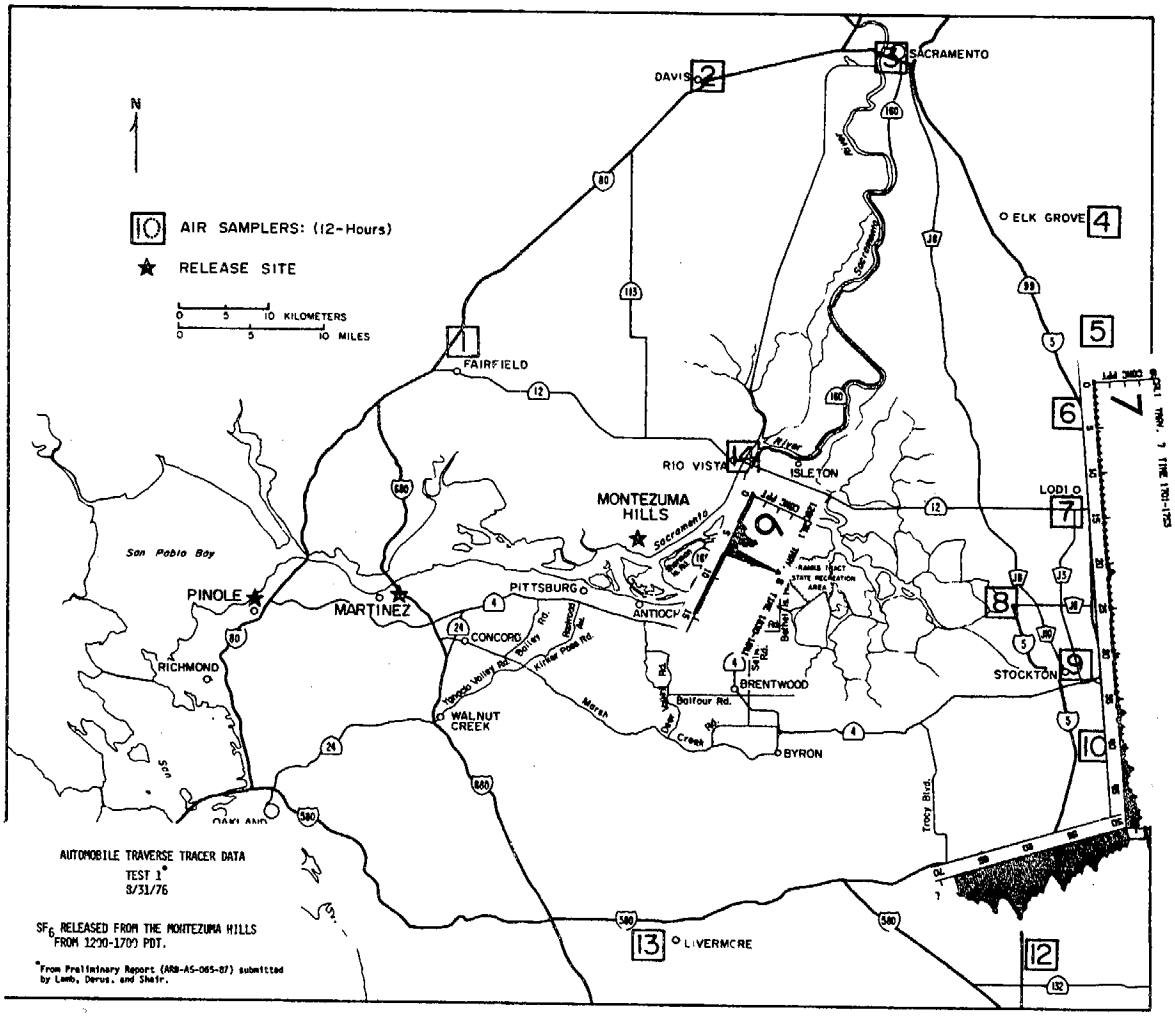



Figure 10. Overview of automobile traverse $SF_6$ data.

TEST 1

8/31/76

Auto Traverses:

6 1630 - 1641 PDT, $SF_6$(max) = 1223 ppt

7 1701 - 1753 PDT, $SF_6$(max) = 64 ppt

$SF_6$ released from the Montezuma Hills from 1200-1700 PDT.

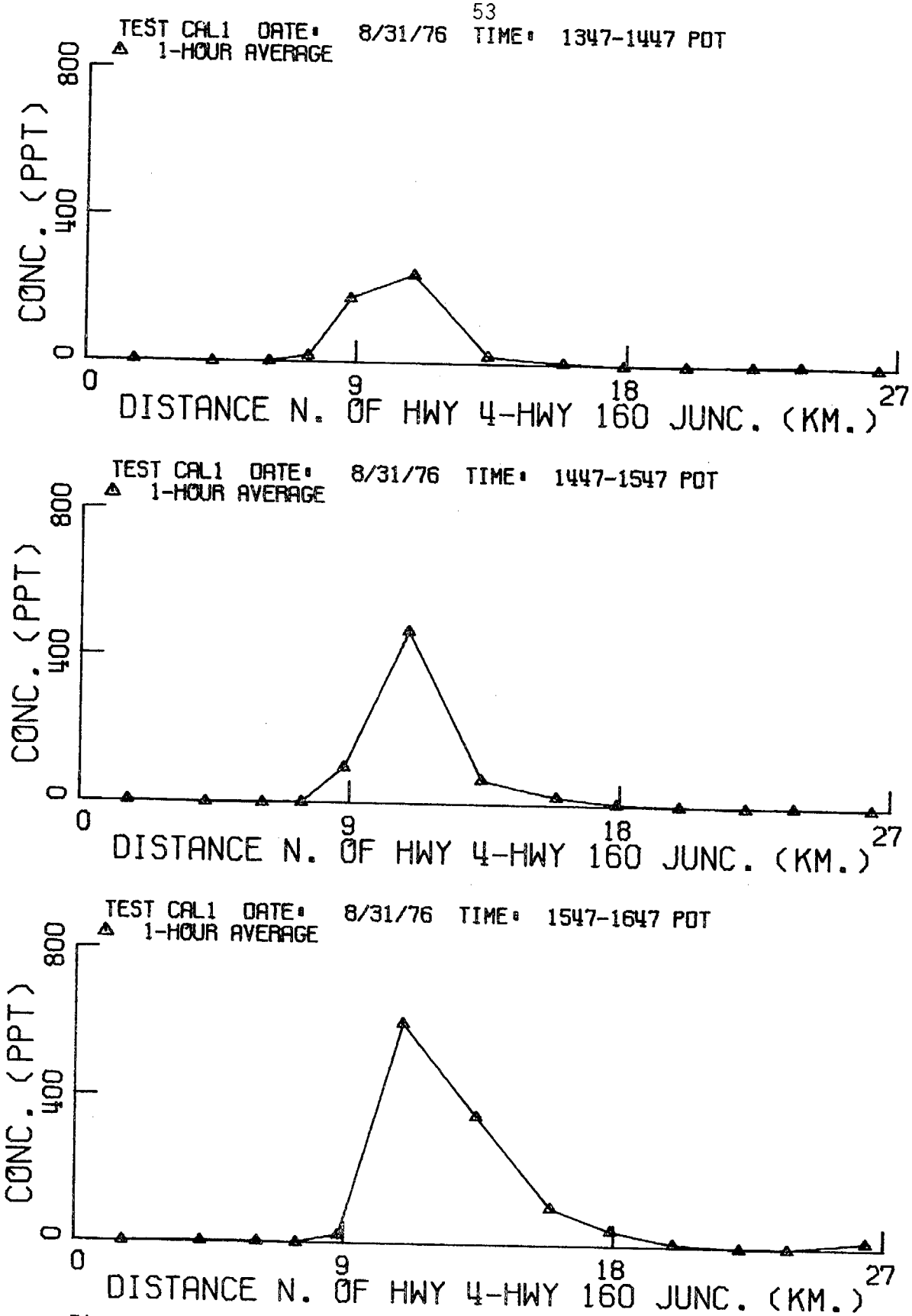



Figure 11. Hourly averaged crosswind $SF_6$ profiles measured along Highway 160.

hourly plume was 72 km wide and was centered approximately 10 km north of Stockton. Significant levels of $SF_6$ were detected during three hours along Highway 99. The tracer emitted during a five-hour period took only three hours to pass, implicating the existence of somewhat stagnant conditions downwind of the Montezuma Hills earlier in the afternoon. The hourly averaged concentrations are plotted as a function of the distance south of Sacramento in Figure 12. An overview of the hourly averaged results is provided in Figure 13.

4.22 Tracer Test 2 (9/2/76)

The purpose of Test 2 was to tag the air moving over the Montezuma Hills during the afternoon Sea Breeze period. Two atmospheric tracers were used: $SF_6$ was introduced upstream at Martinez near existing industrial pollutant sources; $CBrF_3$ was released from the Montezuma Hills. $SF_6$ was released at a steady rate of 11.4 g/sec (1.08 tons/day) from 1100 to 1600 PDT. The release of $CBrF_3$ was not started until 1300 PDT in hopes of waiting for the $SF_6$-tagged air to reach the Montezuma Hills. The $CBrF_3$ was released at a constant rate of 16.6 g/sec (1.58 tons/day) until 1500 PDT.

The average surface wind vectors at Martinez and at the Dow site were $270^0$ at 4.0 m/sec and $270^0$ at 9.2 m/sec, respectively. The overall area average wind direction and speed for the release period was $290^0$ at 4.3 m/sec. The horizontal standard deviation of the winds at the Dow site was $7^0$ for the day. The average mixing height in the area was 830 meters with a maximum of 1500 meters occurring during the late afternoon. There were no clouds, and Pasquill stability classes B-C were assumed to exist. The wind pattern at 1600 PDT shown in Figure 14 was typical for

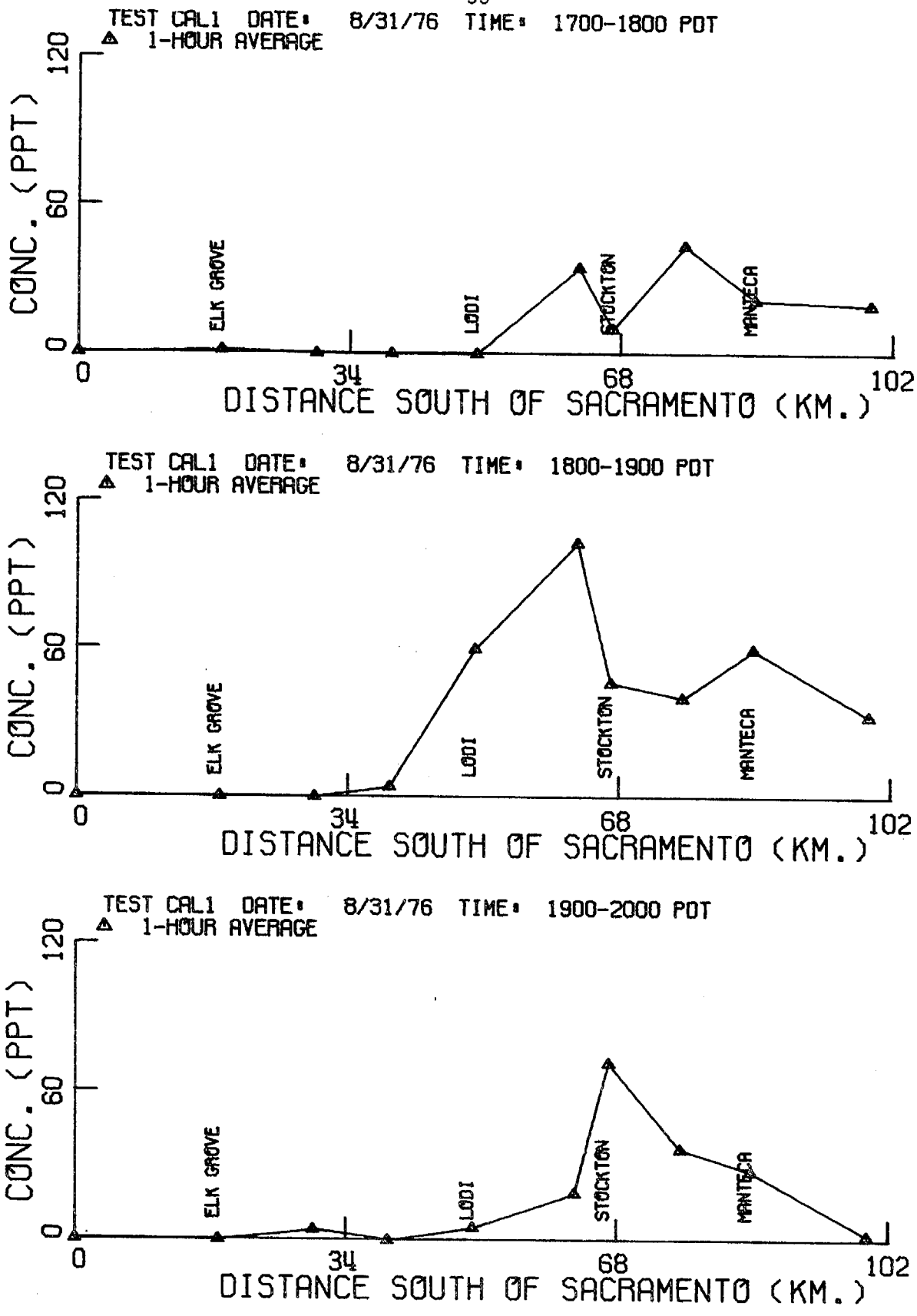



Figure 12. Hourly averaged crosswind $SF_6$ profiles measured along Highway 99.

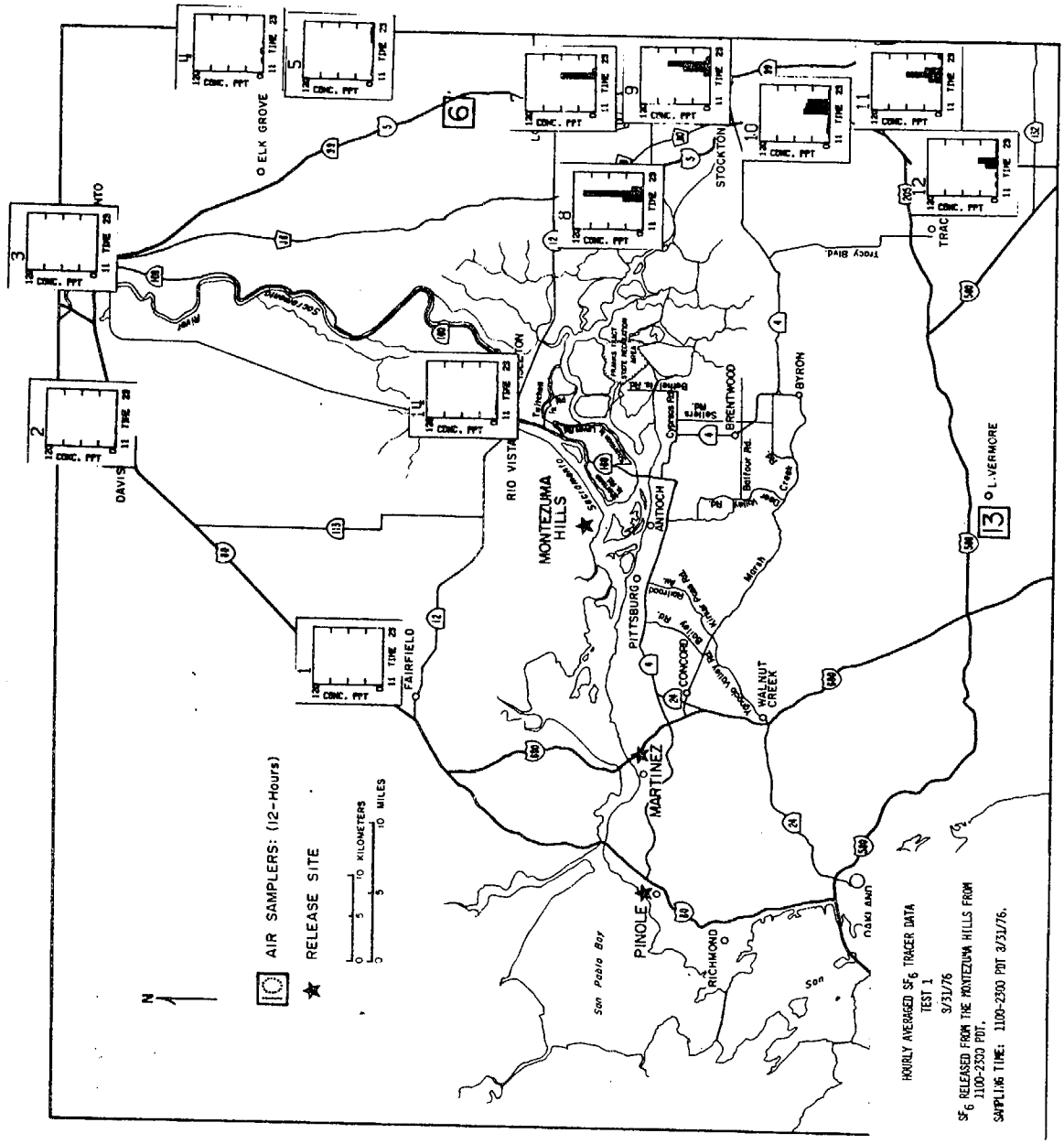



Figure 13. Overview of hourly averaged $SF_6$ data. Full-scale $SF_6$ = 120 ppt.

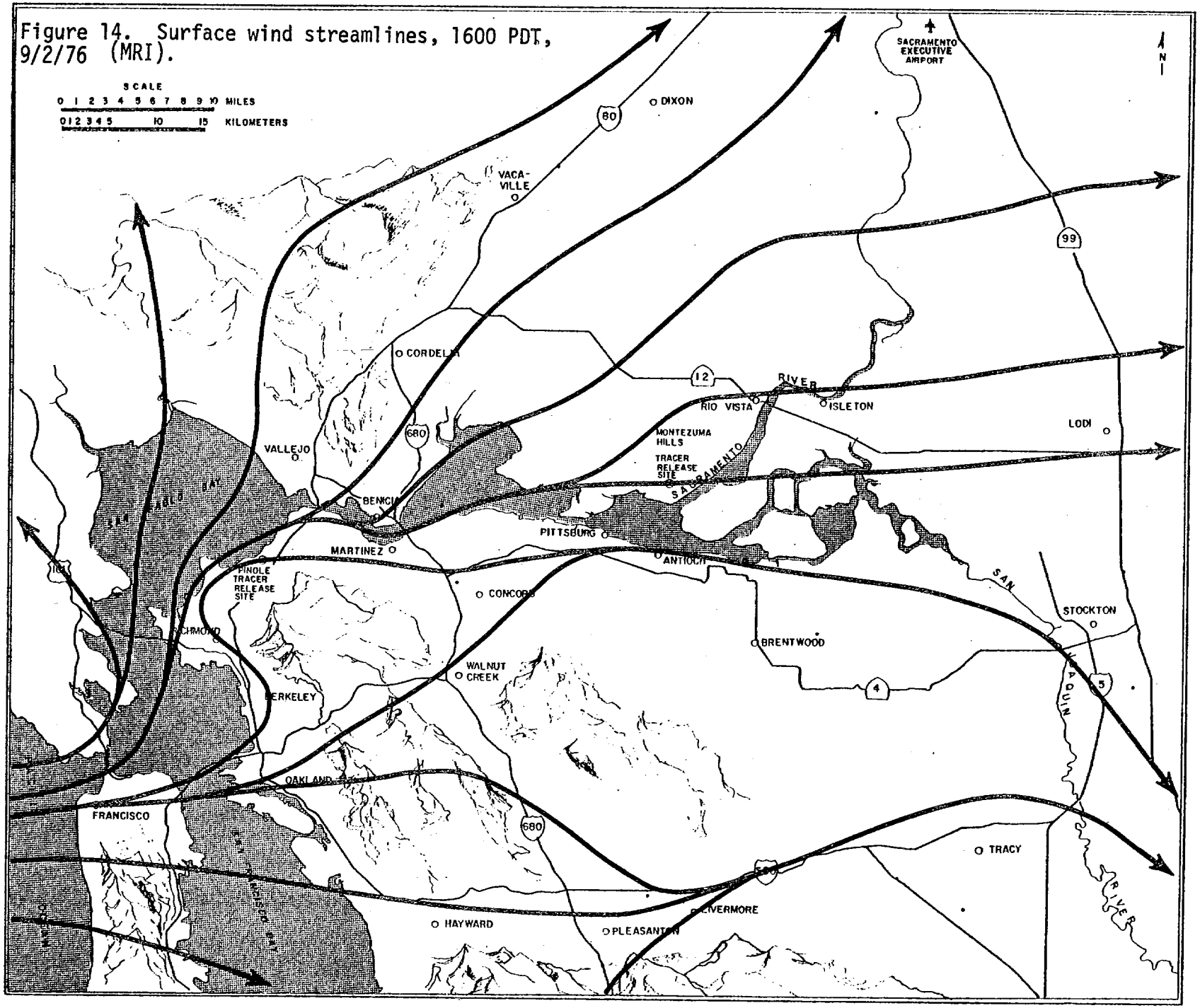



Figure 14. Surface wind streamlines, 1600 PDT, 9/2/76 (MRI).

the afternoon. The pattern appears to be similar to Smalley wind flow type W-6 which occurred 10% of the time in September and 6% of the time on a yearly basis between 1952 and 1955. The peak ozone level was 0.16 ppm observed at Stockton.

Eleven automobile traverses were conducted. The majority of the air tagged by the $SF_6$ tracer did not pass over the Montezuma Hills. However, it did pass through the same downwind zone (i.e., the Tracy-Stockton area) as did the emissions from Montezuma Hills. Traverses 2 and 3 in Figure 15, Traverse 4 in Figure 16, and Traverse 10 in Figure 17 show the sharp, spiked $SF_6$ and $CBrF_3$ plumes immediately downwind of Martinez and Montezuma Hills, respectively, the broad $SF_6$ plume crossing Highway 160, and the location of both tracer plumes crossing Highway 99 south of Stockton. The maximum $SF_6$ concentration observed along Highway 160, 35 km downwind of Martinez, was 33 ppt, while the maximum level seen along Highway 99, 67 km downwind, was 91 ppt. The profile in Traverse 3 indicates that the $SF_6$ trajectory passed south of the Montezuma Hills below Pittsburg and Antioch. The $SF_6$ profile in Traverse 10 suggests that a portion of the tracer from Martinez moved south through the Walnut Creek area towards Livermore.

The $CBrF_3$ plume behaved in a manner similar to that observed during Test 1. The plume crossed Highway 160 approximately 8.2 km north of the Highway 160-Highway 4 junction with a peak concentration of 2168 ppt. It appeared to curve south toward Stockton, crossing Highway 99 with a peak concentration of 300 ppt, 57 km downwind.

Hourly averaged data obtained along Highway 160 and shown in Figure 18 confirm the description drawn from the traverse data. The

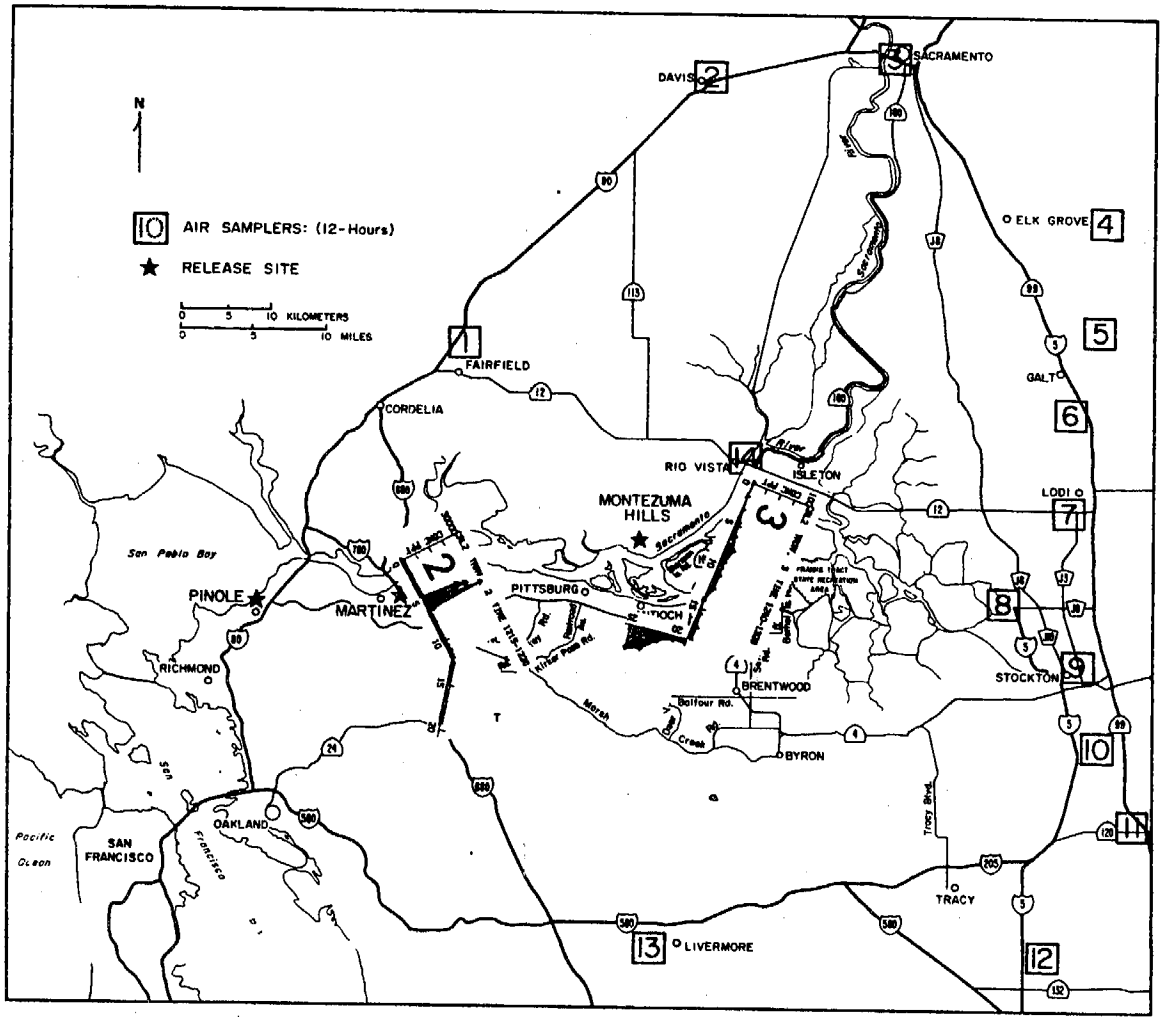



Figure 15. Overview of automobile traverse $SF_6$ data.

TEST 2

9/2/76

Auto Traverses:

2 1215 - 1228 PDT, $SF_6$(max) ≈ 30,000 ppt

3 1240 - 1328 PDT, $SF_6$(max) - 41 ppt

$SF_6$ released from Martinez from 1100-1600 PDT.

$CBrF_3$ released from the Montezuma Hills from 1300-1500 PDT.

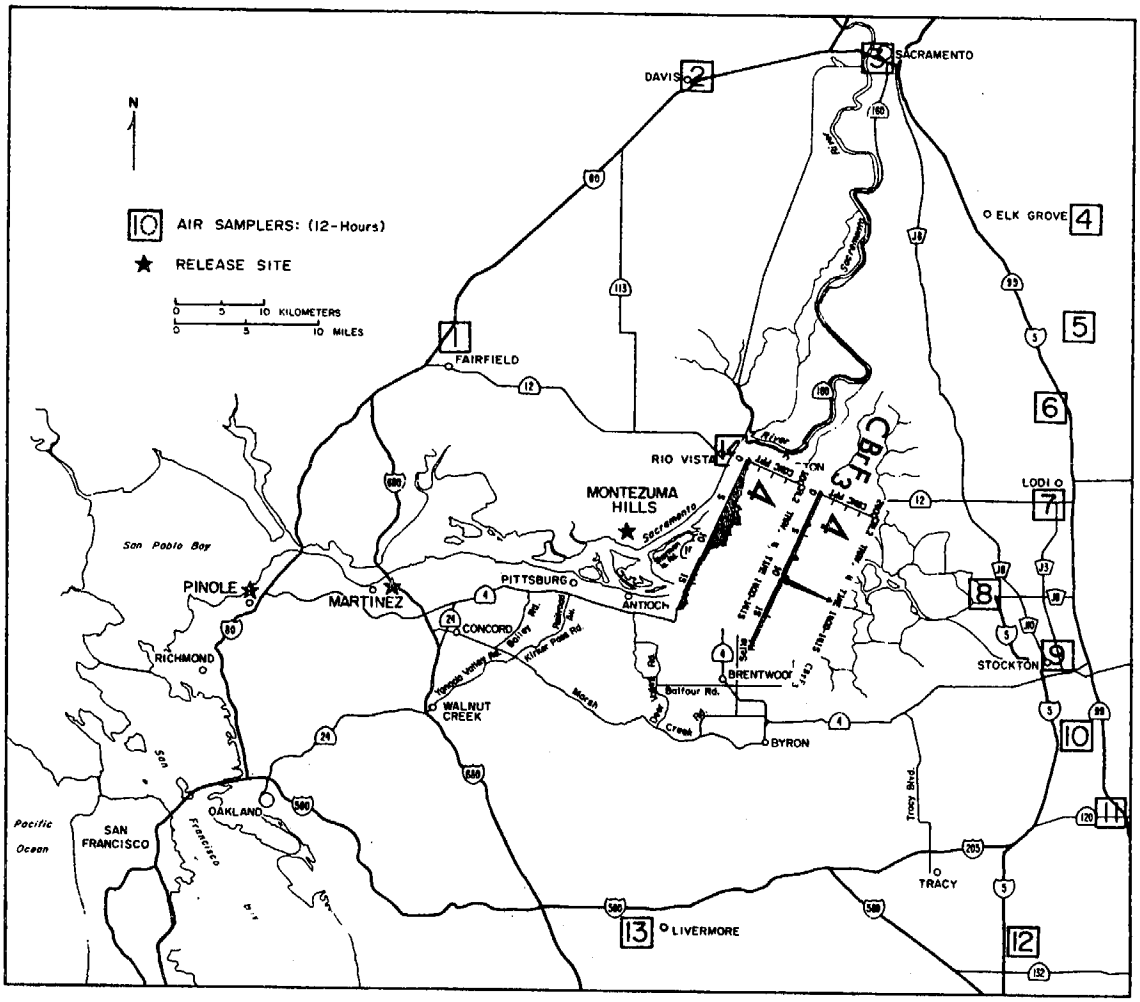



Figure 16. Overview of automobile traverse $SF_6$ and $CBrF_3$ data.

TEST 2

9/2/76

Auto Traverse:

4 1400-1415 PDT, $SF_6$(max) = 33 ppt.

1400-1415 PDT, $CBrF_3$(max) = 2168 ppt.

$SF_6$ released from Martinez from 1100-1600 PDT.
$CBrF_3$ released from the Montezuma Hills from 1300-1500 PDT.

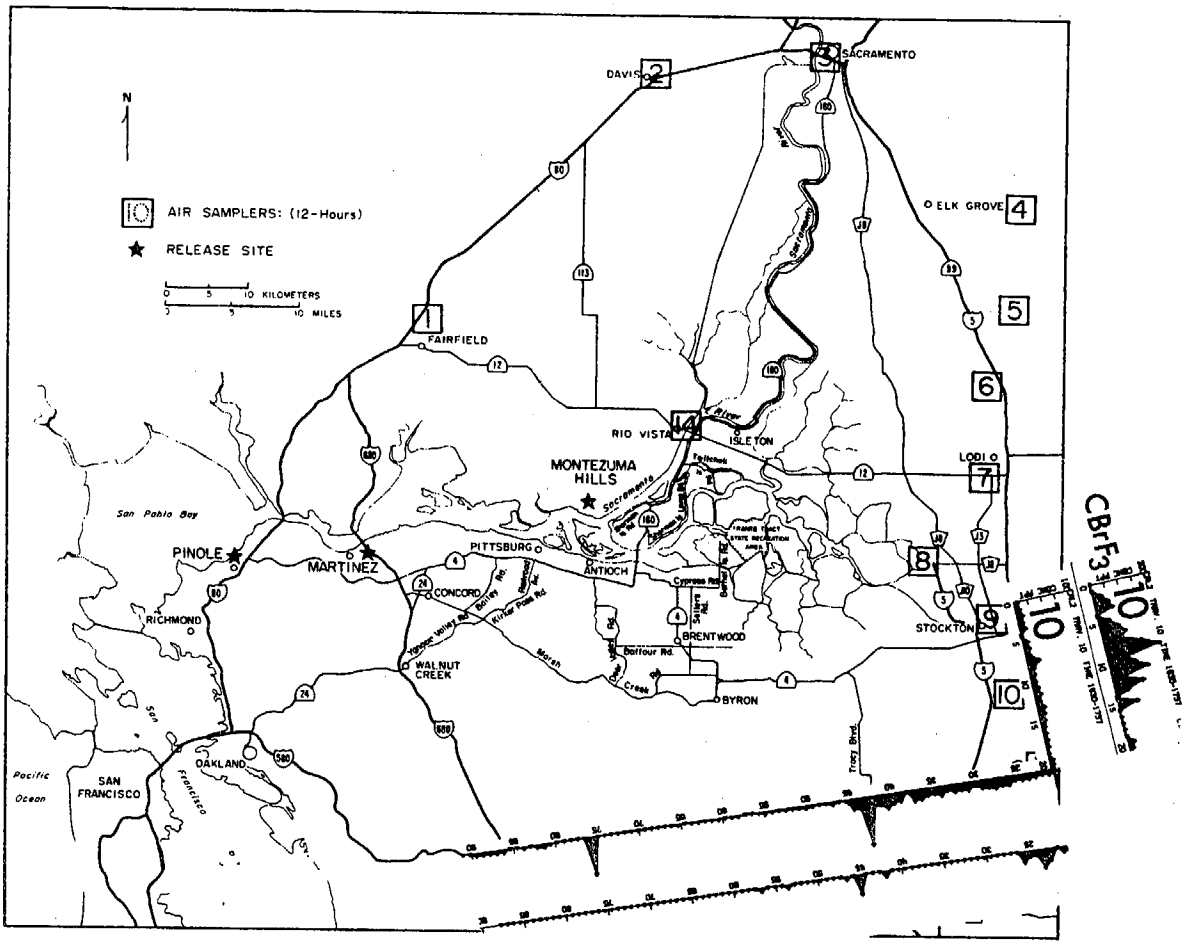



Figure 17. Overview of automobile traverse $SF_6$ and $CBrF_3$ data.

TEST 2

9/2/76

Auto Traverse:

10 1630-1737 PDT, $SF_6$(max) = 91 ppt.

1630-1737 PDT, $CBrF_3$(max) = 300 ppt.

$SF_6$ released from Martinez from 1100-1600 PDT.

$CBrF_3$ released from the Montezuma Hills from 1300-1500 PDT.

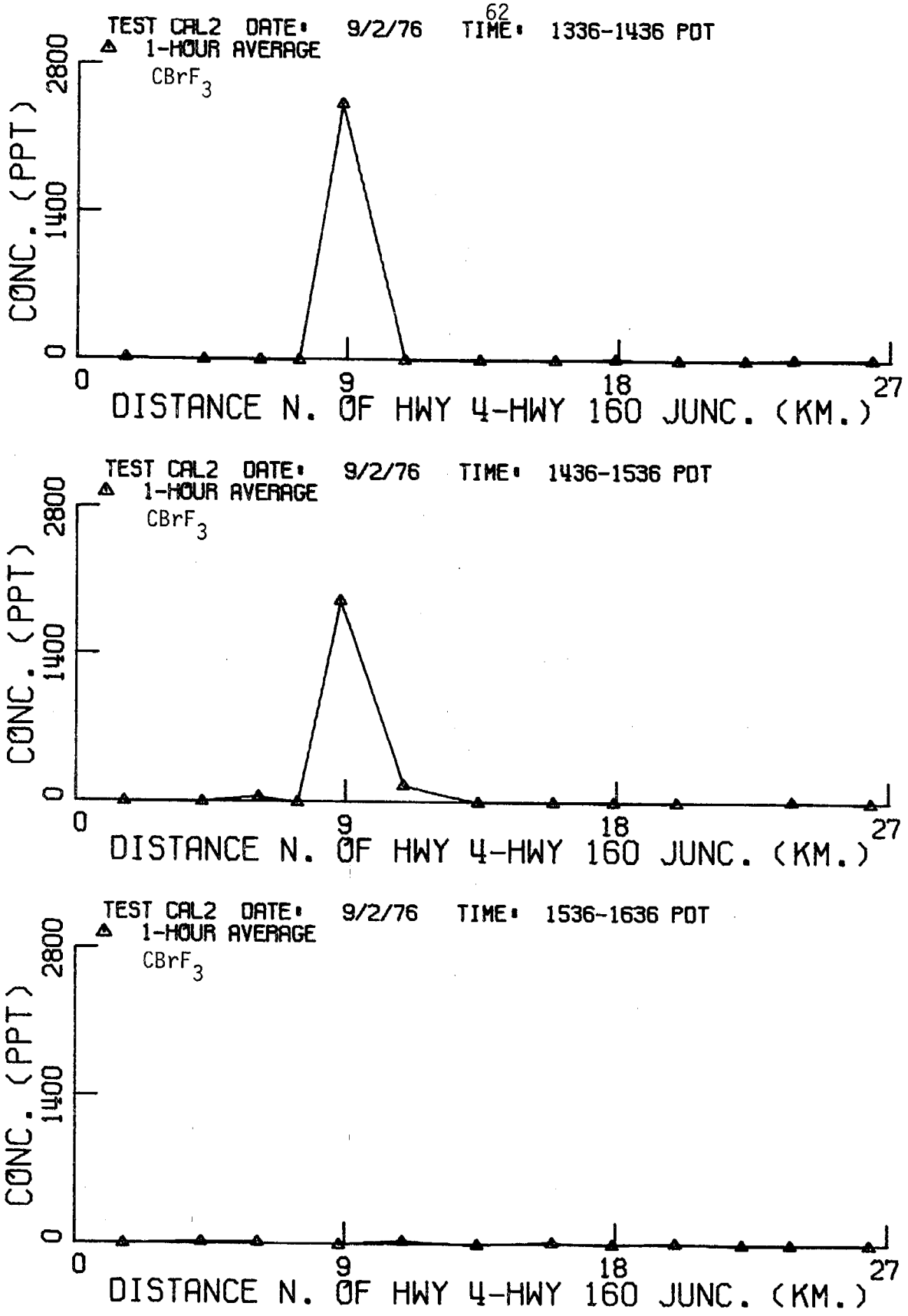



Figure 18. Hourly averaged crosswind $CBrF_3$ profiles measured along Highway 160.

$SF_6$ profile stretches along Highway 160 for 26 km with a maximum of 17 ppt as shown in Figure 19. The maximum hourly averaged concentration of CBrF3 along Highway 160 was 2427 ppt observed 8.8 km north of the Highway 160-Highway 4 junction. The overview map in Figure 20 shows the widespread detection of $SF_6$ during the test period. The data shown in Figure 21 indicate that the plume reached Stockton at about 1600 PDT, which corresponds to an average transport wind speed of 4 m/sec (14 km/hr). The maximum $SF_6$ concentration along Highway 99 was 21 ppt observed approximately 9 km south of Stockton at 1800 PDT. In this test, measurable levels of $SF_6$ were obtained during the night and early morning at several stations along Highway 99. These levels were less that 10 ppt; they suggest that possibly the tracer emitted near the end of the release period from Martinez was transported into the Stockton-Tracy area where it remained for several hours under nighttime stagnant conditions. As in the first test, material emitted from the Montezuma Hills reached the Stockton area and was directed south into the San Joaquin Valley. In addition, material emitted from Martinez, near the Carquinez Strait, reached the same area and appeared to be moving south into the San Joaquin Valley.

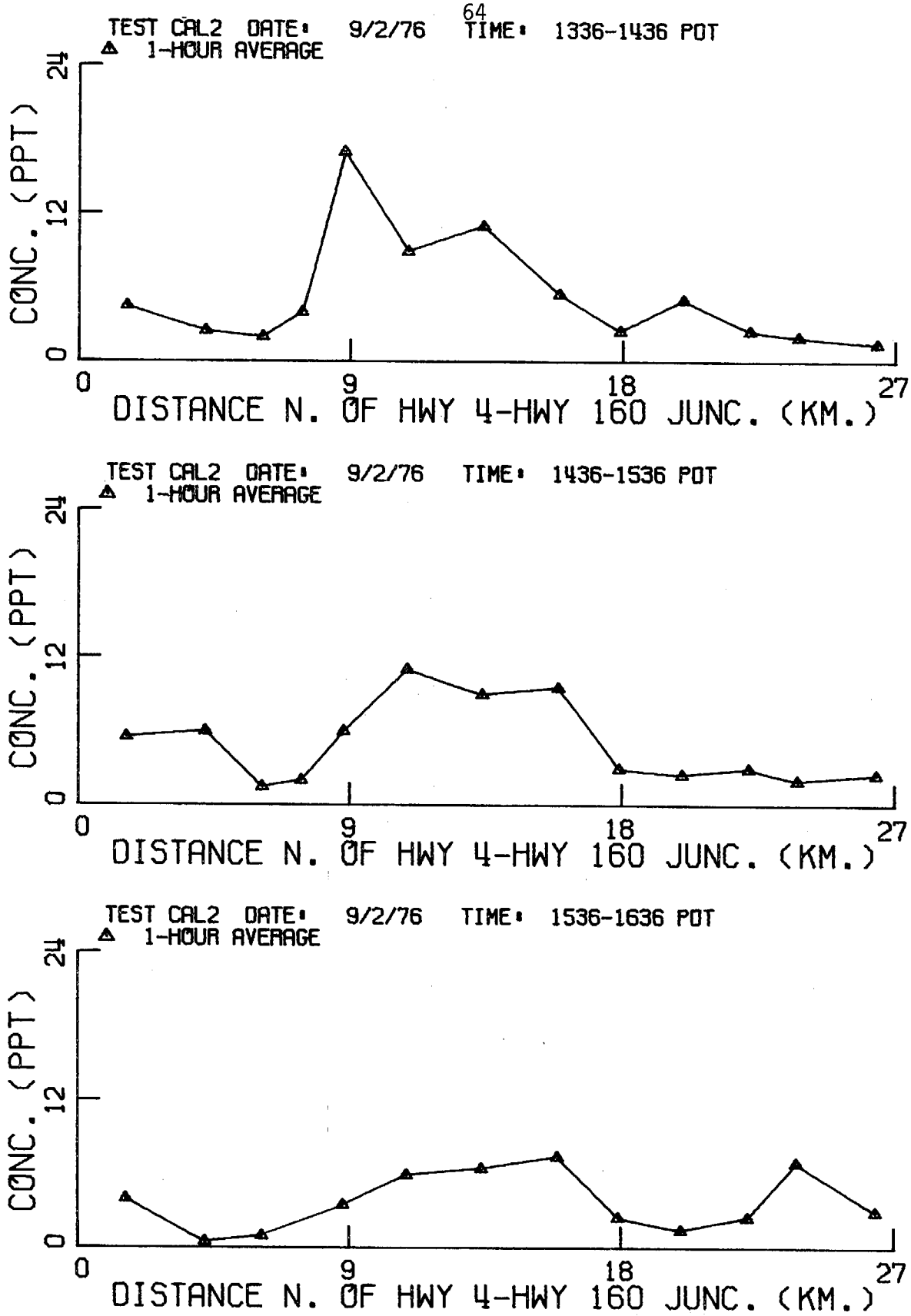



Figure 19. Hourly averaged crosswind $SF_6$ profiles measured along Highway 160.

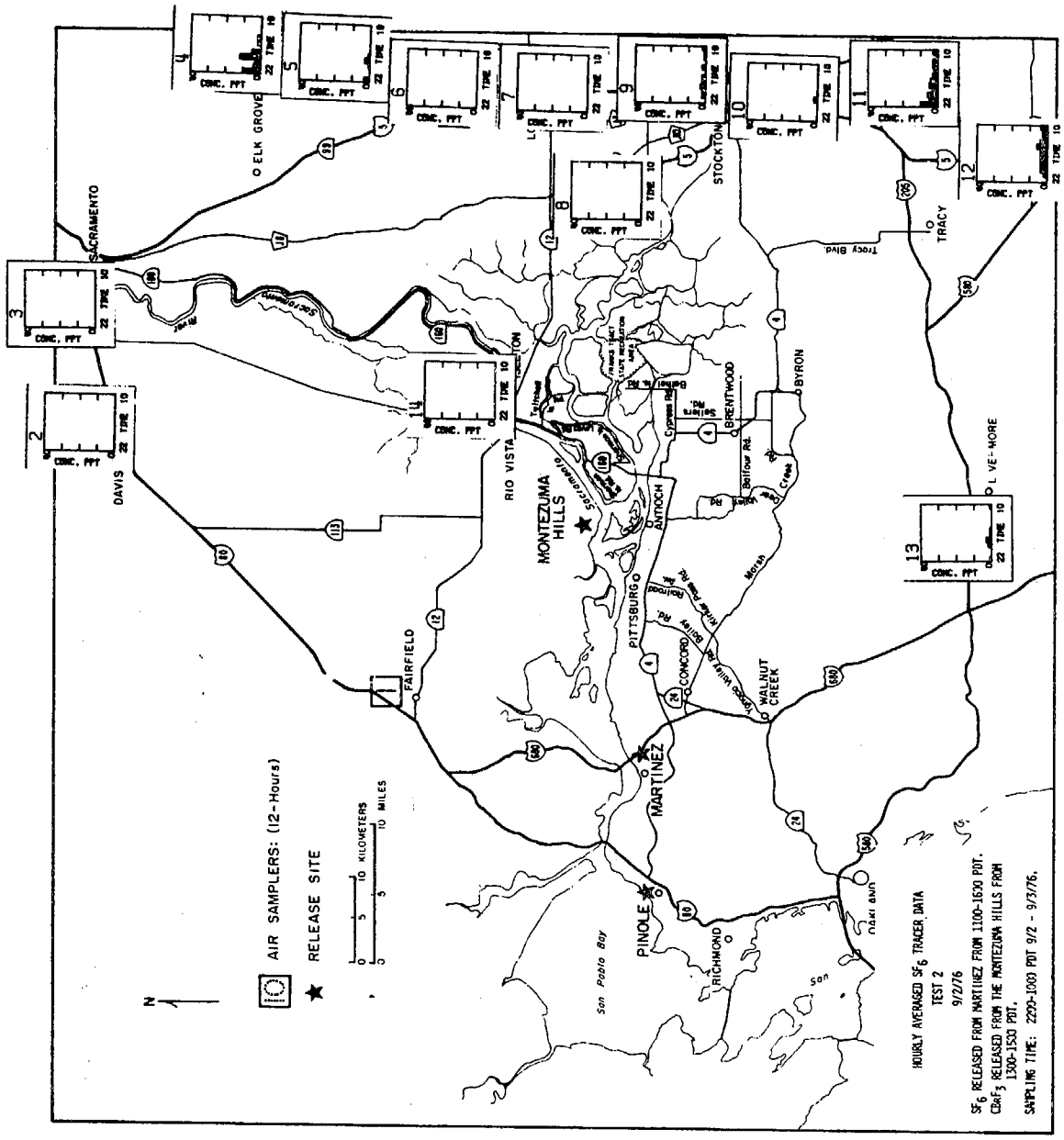



Figure 20. Overview of hourly averaged $SF_6$ data. Full scale $SF_6$ = 40 ppt.

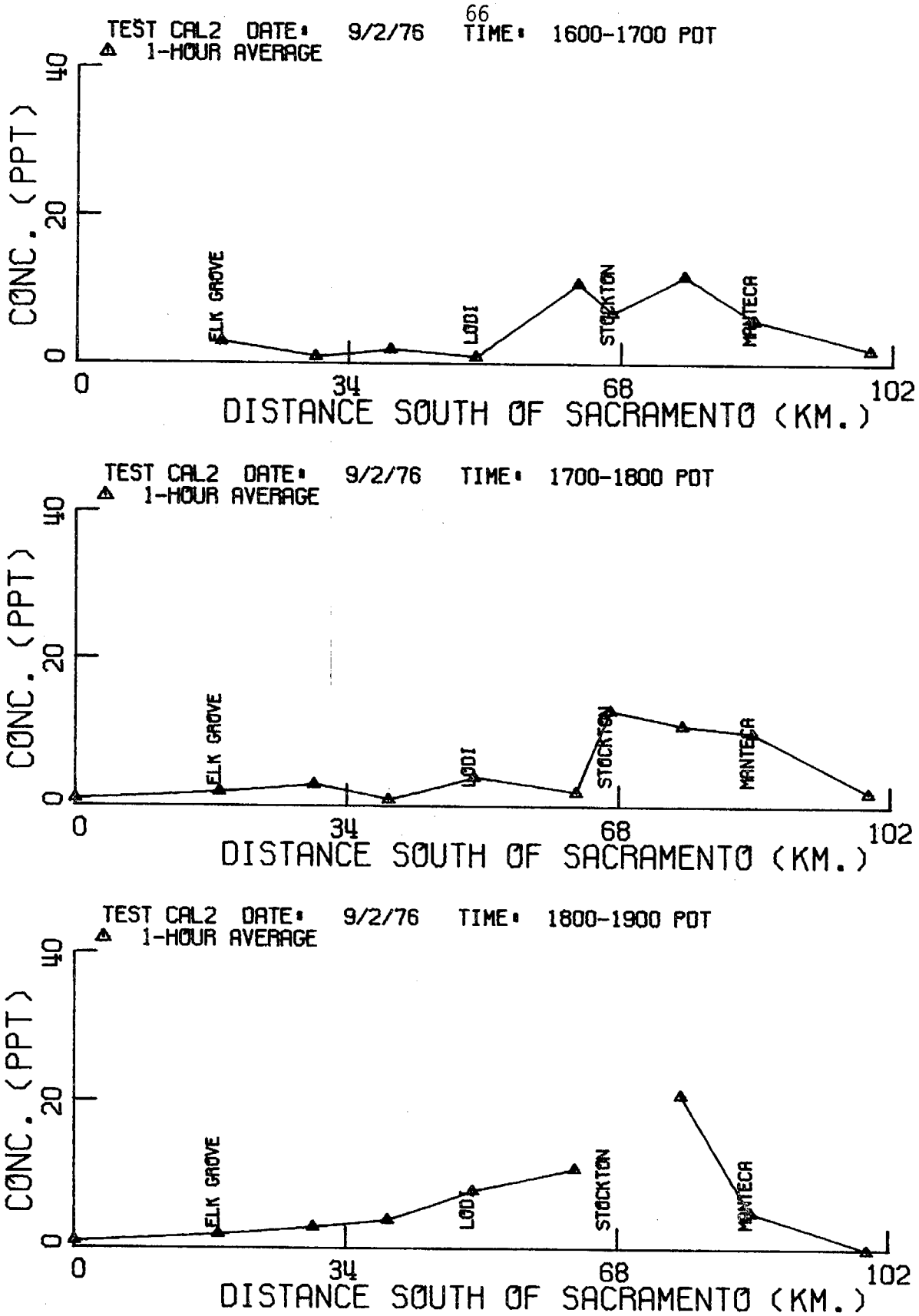



Figure 21. Hourly averaged $SF_6$ profiles measured along Highway 99.